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Resource Recovery from Plastic and Glass Wastes

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Santa Monica, CA

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RESOURCE RECOVERY FROM PLASTIC AND GLASS WASTES

by

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Santa Monica, CA 90404

Contract No. 68-03-2708

Project Officer

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16. ABSTRACT

This research program was initiated with the overall objective of assessing and evaluating State-of-the-Art for recovery of glass and plastic from solid waste.

Literature was gathered from numerous sources, contacts were made with industrial and recycling organizations, and questionnaires were distributed among applicable firms involved in glass and plastic recovery. Data derived from literature was collected, reduced and evaluated for technical,economic, and environmental content.

Both glass and plastic industries were characterized by processes, material flows, economic dynamics, and waste generated. Methods for recovery, (e.g., collecting, aggregating, processing and transportating), and recycling were identified. Economic and environmental parameters are provided. Currently, labor-intensive source separation of glass and plastic predominate,although mechanical recovery will achieve greater importance in the years ahead.

Finally, research activities and State-of-the-Art activities in foreign countries are identified. Where feasible, their relative importance is assessed.

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FORWARD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This publication reports on state-of-the-art for recovering glass and plastic wastes from solid wastes. It provides technical, environmental, and economic evaluation of information derived from literature.

Francis T. Mayo, Director
Municipal Environmental
Research Laboratory

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Both industries were characterized by processes, material flows, economic dynamics, and waste generated. Methods for recovery, (e.g., collecting, aggregating, processing, and transporting), and recycling were identified. Economic and environmental parameters are provided. Currently, labor-intensive source separation of glass and plastics predominate, although mechanical recovery will achieve greater importance in the years ahead.

Finally, research activities and State-of-the-Art abroad are identified. Where feasible, their relative importance is assessed.

This report was submitted in fulfillment of Contract No. 68-03-2708 by Pacific Environmental Services, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period May 1978 to January 1980, and work was completed as of July 1, 1980.

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Roy Sakaida, Ph.D., Project Director
Jon Michael Huls, Project Manager

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SECTION 1

EXECUTIVE SUMMARY

INTRODUCTION

The objective of this report is to define the state-of-the-art for plastic and glass waste recovery as determined from available literature. Resource recovery technologies, both mechanical and labor intensive, are assessed for municipal and industrial waste sources. Where data are available, these technologies are discussed in terms of technical, economic, environmental, and social aspects. Current trends in plastic and glass waste recovery practices outside the United States are provided. Research efforts are identified, and research needs to enhance recovery of wastes are addressed.

The report is divided into 8 sections listed below:

(1) Executive Summary
(2) Conclusions and Recommendations
(3) Manufacturing and Industrial Background for Plastics and Glass
(4) State-of-the-Art for Plastic Wastes Recovery
(5) State-of-the-Art for Glass Waste Recovery
(6) Environmental and Economic Evaluation
(7) State-of-the-Art for Plastic and Glass Waste Recovery Abroad
(8) Research on Plastics and Glass Waste Recovery

With the exception of Sections 4 and 5, plastics and glass discussions are integrated into each section on a subsection basis. This treatment is warranted in order to avoid confusion and allow a presentation in a sequential fashion.

Study findings are discussed in the following subsections.

WASTE GENERATION, SOURCES, RECOVERY AND IMPACTS

Three sources of plastic and glass waste generation were identified: industrial, commercial, and municipal. Industrial waste is considered to be any material generated and discarded during the manufacturing process. Commercial waste is that waste generated during the final stages of product lines before consumer usage. Municipal waste represents post-consumer waste, as well as some industrial and commercial discards.

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Plastic Waste Generation

Plastics production in 1977 totaled 15,411 Gg (33,948 million lbs). Of that amount, approximately 80 percent was thermoplastics, which are amenable to remelting and, thus, refabrication, to a certain extent. The largest single end-use for plastics is in packaging, although most plastics are utilized in long-term uses. As a result, plastic wastes found in the municipal waste stream are normally plastics packaging. No hard data exist to indicate exact quantities of plastics recovered from waste streams. Estimates indicated that of the 7,500 Gg (16,500 million lbs) generated annually from all sources, about 2,200 Gg (4,850 million pounds) were recovered, primarily through industrial recycling. Currently, about 3 percent of the municipal waste stream is comprised of plastics.

Plastics Wastes Resource Recovery

Most industrial and commercial plastics wastes are relatively clean as non-mixed species. It is, therefore, economical to recover these materials. In-house recovery practices are well established within the industry and scrap dealers provide the remaining recovery potential.

Contaminated and mixed plastics have limited usage for recycling. Plastics appear to be incompatible between different family types and produce products with less than desirable chemical and physical properties during manufacturing.

Segregation of plastics from the municipal waste stream is a practice currently in its "infancy". Both mechanical and labor intensive modes, though, do exist for recovery. Limited research indicates that certain thermoplastics can be segregated, and that selected mixtures coupled with special binders can be developed for use in secondary products. Secondary product markets are not developed, however, and the processes for segregation and mixing/bonding are not commercially available.

Reuse strategies have shown that clean and single material plastic waste streams derived from municipal waste (PET, for example) can be collected and recycled. However, this is limited and is useful only for beverage packaging.

Except on such limited basis, plastics materials recovery from the mixed municipal waste stream appears to be technically or economically infeasible at present. The greatest potential for successful plastics waste recovery seems to be the derivation or recovery of energy from combustion of a mixed plastics/organics waste fraction in the municipal waste stream, or to just enhance volume reduction through various forms of thermal treatment by utilizing the high energy value of plastics.

In the latter, the presence of plastics enhances combustion due to a high Btu content. As waste contains a number of noncombustible items and significant quantity of moisture, plastics can be an important offsetting combustible fraction.

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Thermal treatment can be grouped into three general categories:

- Large scale and modular incineration (with and without energy recovery)
- Pyrolysis
- Preprocessing for refuse-derived fuel

For each of these methods, proponents desire the high energy content of plastics to enhance the overall energy content of the solid waste. Plastics found in MSW have heating values in excess of 42 kJ/g(19,000 Btu/lb). Refuse heating values range near 11 kJ (5,000 Btu/lb). As a comparative point, coal has a typical energy content of 28 kJ/g (12,000 Btu/lb).

An additional benefit of the thermal treatment systems is the potential for volume reduction of solid waste by as much as 90 percent.

Thermal treatment systems can meet air quality standards with large expense and difficulty. The ash and sludges are considered to be biologically inert, but some hazardous constituents may be present. Hence, they must be properly disposed. Thermal treatment systems are detailed in Sections 4 and 6.

Low-technology recovery systems such as source separation are often categorized as being labor-intensive. These recovery systems have met with limited success. The major reasons are that insufficient markets exist for the recovered materials, and recovery procedures are just beginning to be developed. One system in California (Poly II) has had a reported initial success in recovering plastics from mixed plastics obtained from municipal sources. In Michigan, PET bottle recycling is commercially established.

Environmental and Economic Impacts

Environmental and economic impacts of recovering energy values from the plastic portion of the municipal solid waste stream are difficult to quantify for any municipal source. Several experimental results indicate that burning of plastics would impose minimal environmental impacts. Insufficient data exist on the feasibility of new enterprises related to plastics waste recovery and recycling.

Plastic Waste Recovery Research

Research activities continue at the governmental and industry levels. The Bureau of Mines still conducts technical research on segregating plastic. A new thought expressed is that plastics of uniform variability (uniform by source and constant composition) may be recyclable even though materials are mixed. Specifications and secondary product market development must be conducted in order to enhance such application.

State-of-the-Art for Plastics Waste Recovery Abroad

It appears that other countries are in similar conditions as the United States. However, Japan and Europe appear to be slightly advanced in collection and reuse due to more extreme energy and materials shortages. The advantage of surplus labor is maximized in underdeveloped and some industrialized countries.

One aspect is that economy of scale is favorable in smaller-sized enterprises.

Conclusion

In conclusion, the state-of-the-art of plastics waste recovery is of limited status when assessed for the municipal waste stream. It appears that for future recovery of plastics, burning or tertiary recovery to recover energy values will be the predominant method. Again, such recovery can be attempted only for plastic entrained in mixed municipal refuse. Additional research is needed to establish markets for recovered plastics waste and secondary materials made from these. The experience of other countries may prove valuable in assessing any future recovery of plastics waste. The larger percentage of plastics in some foreign waste streams, and the relative lack of petroleum products has made recovery more feasible. Important points are that enhancement of plastics waste recovery requires either (1) a smaller range of diversity amongst plastics types to facilitate technical recovery, or (2) significant sources and uses for making recovery economical.

Glass Waste Generation

Glass production in 1978 was estimated to be about 18 Tg (20 million tons). Of this amount, about 70 percent was container glass products. The remaining production types of glass, in decreasing quantities, are flat glass, pressed and blown glass, and wool fiberglass.

Commercial glass wastes cannot be quantified because of the diversity of the industry. The actual amount of glass waste generated is considerably higher than that from the industrial segment, but it is not as high as that from the municipal segment. A major contributor to the generation of glass waste is contamination of the glass with substances such as foods, paints, and of course, breakage.

The amount of glass waste in the municipal waste stream is about 10 percent. This amount represents approximately 70 percent of the total glass production. The amount of glass waste in the municipal solid waste stream is not necessarily 70 percent of that year's production, since the useful life of glass articles varies. Data indicate that more than 90 percent of the glass in municipal waste streams is of the container type. This is expected, since container glass often has a relatively short useful life.

Glass Waste Resource Recovery

It is the current practice of essentially all the glass manufacturing plants to recycle all their waste glass. Since this glass is of known composition and relatively uncontaminated, the manufacturer attempts to utilize all available waste glass, either through direct revenue or sale to a broker.

Purchased cullet (foreign cullet) is used less extensively in batch make-up. Several reasons for this include contamination, unknown compositions, and color contaminants. Based on strict product specifications and competition within the industry for quality ware, these factors discourage foreign cullet utilization. Some segments within the industry rarely use foreign cullet in their batches. For example, flat glass and certain pressed and blown segments cannot use foreign cullet in their batches since it could affect the quality of their glassware.

Even so, the container glass segment has used known foreign cullet in their batches. It has been reported that the container segment could use all potentially recoverable clean and color-sorted cullet. However, at the present, clean cullet is limited. Recycling centers provide small quantities of clean cullet, and the high technology recovery systems provide potential for cullet recovery. These systems provide either mixed cullet or separated cullet. Still, the amount of contamination and marketing conditions limit its general acceptance.

Efforts to recover glass waste from commercial sources are enhanced by combined efforts of the glass manufacturer, intermediate processors, and recycling centers. This source tends to generate larger volumes per unit source, although it may be contaminated.

Municipal glass waste recovery has been limited to source separation and pilot high technology mechanical recovery systems. Source separation practices are dispersed geographically across the United States. Most of these programs are community involved recycling efforts. Several privately funded source separation programs are showing economic feasibility. Limiting factors for these recovery techniques appear to be economic and relate to transportation, labor, and collection and processing efficiencies. In most situations, it is economical to recover glass with simultaneous recovery of aluminum and paper to offset the high transfer and processing costs associated with glass.

Environmental and Economic Evaluation

Adverse environmental impacts associated with source separation systems are minimal. Any excessive fuel usage by the consumer will probably be offset by the reduction in landfill requirements.

Municipal waste recovery through high technology systems is limited to either froth flotation or optical sorting. These techniques are proven in the minerals industry, but have had limited success for glass recovery, both on experimental and full-scale basis. Economics prohibit exclusive recovery of glass. Rather these systems are used as a subcomponent to an overall recovery system.

The environmental and economic impact for glass waste recovery cannot be fully assessed since it is only a subsystem to the overall recovery system. From the literature, there appear to be no adverse environment impacts associated with glass recovery.

Glass Waste Recovery Research

Foremost, a market for the recovered glass must exist. Presently there are only limited markets. One area of research that has been promising for glass waste recovery is its use in secondary products. Products such as glasphalt and glass foam insulation demonstrate the technical feasibility of using glass waste for secondary products.

An area of some interest is reuse of products. The ENCORE! system, a wine bottle washing operation, depends on free market forces. It is both profitable and effective. Although there is a question of safety, no serious problems have been encountered to date.

Technology Abroad for Glass Waste Recovery

Technology here and abroad is generally parallel in its development. Outside the United States, labor-intensive recovery practices are used most commonly.

Conclusion

In conclusion, the state-of-the-art of glass recovery is that industrial and commercial sources conduct the majority of clean recycling. Municipal sources produce the greatest quantities of waste glass. Recovery on the municipal level is limited to source separation and large-scale recovery facilities. Market development remains the most serious research question facing glass recovery.

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SECTION 2

CONCLUSION AND RECOMMENDATIONS

This report has assessed the state-of-the-art resource recovery for plastics and glass wastes. The following summarizes the major findings and research needs in areas considered essential for any successful future recovery of plastics and glass wastes.

CONCLUSIONS

State-of-the-Art

Plastics--

- Industrial and commercial sources efficiently recycle using simple, proven technology. The main reasons are waste materials are concentrated, relatively uncontaminated and usually of known quality and composition.

- No proven commercial scale recovery system singularly effects recovery of waste. Rather, such materials are recovered as one component of an over-all recovery-collection approach.

- Secondary products, on the whole, have not had specifications developed for product reuse. This has acted as a barrier to increased utilization since reuse processes have not necessarily been standardized.

- Combustion and energy recovery hold the greatest promise for recovery of the bulk of the plastics fraction of the solid waste stream due to the number of different types of plastics and the differing degrees of degradation of components.

- Source separation from the industrial to the residential levels constitutes the only significant recovery of waste from municipal waste sources.

- For the immediate future, industrial and commercial sources will comprise the majority of recycling activity. Recovery from post-consumer wastes must overcome significant market, institutional, technical, transportation, and specification barriers in order to compete successfully with virgin products.

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Glass--

- Glass manufacturers claim that 25 percent of the post-consumer waste stream could be recycled right now. Transportation and collection/delivery problems and contaminant levels restrict this.

- Industrial and commercial sources efficiently recycle using simple, proven technology. The main reasons are waste materials are concentrated, relatively uncontaiminated and usually of known quality and composition.

- Municipal sources of wastes are most often mixed with other components of refuse; hence, recovery is difficult with poor economics; also, the ease of obtaining raw materials, prevents a significant recovery incentive.

- No proven commercial scale recovery system singularly effects recovery of waste. Rather, such materials are recovered as one component of an over-all recovery-collection approach.

- Recovery is often inhibited due to the lack of efficient source separation processing equipment.

- Standardized specifications have not been developed for secondary products which acts as barrier to glass reuse.

- Mechanical recovery systems for glass wastes have primarily originated from other industries such as mining. They lack proven usage in waste separation where moisture, composition, physical properties, and economics vary widely.

- A national market for mixing color glass cullet could significantly enhance recovery of glass wastes from municipal sources by simplifying collection and processing.

- Source separation from the industrial to the residential levels constitutes the only significant recovery of waste from municipal waste sources.

- For the immediate future, industrial and commercial sources will comprise the majority of recycling activity. Recovery from post-consumer wastes must overcome significant market, institutional, technical, transportation, and specification barriers in order to compete successfully with virgin products.

Environmental and Economic Considerations

Plastics--

- Waste recovery rates are negligible; hence, environmental and economic impacts associated with recovery processes can only be speculative at this time. Rather, the continued disposal of these valuable products can only be a negative impact both environmentally and economically.

- There is no concrete data available on emerging secondary product recycling to quantify potential environmental and economic impacts. It is desirable to recover whenever feasible, but the lack of data precludes assessing breakeven points and other indicators of success.
- Source separation methods such as curbside collection and buy-back recycling do not adversely impact the environment, when operated efficiently. In all cases, recovery of waste more than balances any associated negative impacts.
- The potential for recovery from concentrated sources is enhanced by increasing raw material, energy, and oil product costs.
- Emissions from energy recovery will vary as solid waste composition varies; hence, any assessment is dependent on site specific information.
- Through use of proven air control technologies, emissions from plastics waste combustion would be insignificant when compared to national ambient emissions. Tests on burning three major types of plastics, under controlled air conditions, showed insignificant generation of emissions.
- At present, municipal refuse-fired incinerators and steam generators, not exceeding 250 mm Btu/ton capacities, need only meet national particulate emission standards.
- Recent data indicate that residues from combustion processes might contain some hazardous constituents in trace amounts. Glass and plastics have not been identified as contributors.
- Plastics do not exist in substantial amounts in the waste stream at this time to justify mechanical processing for recovery into individual types.
- For the immediate future, industrial plastic scrap will remain the most recoverable for economic and environmental reasons.
- Source separation conserves energy upon net energy balance analysis.
- Product reuse, i.e., segregation for reuse in a similar form, may have increased value as energy and resource costs rise.

Glass--

- Wastes recovery rates are negligible; hence, environmental and

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economic impacts associated with recovery processes can only be speculative at this time. Rather, the continued disposal of these valuable products can only be a negative impact both environmentally and economically.

- There is no concrete data available to quantify the potential environmental and economic impacts of recycling secondary products. It is desirable to recover whenever feasible, but the lack of data precludes assessing breakeven points and other indicators of success.
- Curbside collection and buy-back recycling centers do not adversely impact the environment, when operated efficiently.
- The potential for recovery from concentrated sources is enhanced by increasing raw material, energy, and oil product costs.
- Glass, as a solid waste disposal component, does not adversely affect the environment. However, utilization of glass reduces the demand for landfill space.
- Increased use of cullet in glass making furnaces is reported to reduce the overall emissions from such operations.
- Increased use of cullet in glass producing furnaces can effectively reduce energy demand.
- Secondary product uses, such as glasphalt, do not provide significant economic incentive to offset high, mechanical processing costs.
- Economics preclude the singular recovery of glass wastes from mixed wastes utilizing mechanical means.
- The return (revenue) on glass as a recyclable item is less per unit weight than other higher priced waste items such as aluminum.
- Source separation conserves energy upon net energy balance analysis.
- Product reuse, i.e., segregation for reuse in a similar form, may have increased value as energy and resource costs rise.

Plastics and Glass Recycling Abroad

- Foreign plastics and glass recovery methods have limited application in the United States, due to differing waste management objectives and waste stream types.
- Incentives for recovery in foreign countries stem primarily from energy and resource scarcity, two areas that are of increasing importance to the United States.
- Foreign technologies emphasize the human energy element in processing operation.

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- More extensive research efforts are needed to properly evaluate the applicability of foreign technologies.

RESEARCH AGENDA

The extent to which glass and plastic waste is recovered and recycled depends on a combination of important and interrelated conditions and issues, as discussed throughout this document. The research agenda must necessarily consider these factors which are normally regarded as "constraints" including marketing and institutional, financial and economic, political, and technological topics.

Research recommendations are, therefore, presented first in terms of these topics, and then specific recommendations for glass and plastic are made.

Marketing and Institutional

Constraints placed on scrap materials have inhibited the marketing of such materials. Constraints have included restrictions to modifications of existing solid waste practices such as limits on landfill salvaging, economic development restraints for smaller scale waste-based industries, and consumer attitudes toward the purchase of waste-derived products (1).

Research Recommendations--

1. Evaluate the Federal role in procurement of products containing recycled materials (for example, fiberglass insulation for construction projects involved in urban renewal).

2. Evaluate the potential for community industry development to utilize urban waste materials including glass and plastics.

3. Determine the potential for developing new vertically integrated glass and plastic waste industries; (e.g., industrial park developments) and who should be responsible for financing?

4. Examine the legitimacy of reuse strategies which do not rely on legislative mandates (e.g., ENCORE! programs)

5. Estimate consumer resistance toward container standardization or development of an ecobottle (one color only)

6. Develop a glass and plastics secondary materials use policy which coordinates Federal programs with state and local government and private industry needs.

7. Evaluate the impact of reuse strategies on recovery methods.

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Economic and Financial

Transportation, financing, market entry and investment discrimination are areas for research (1). Financial "discrimination" is cited as a barrier to certain recovery programs. Mechanical recovery systems are privy to large sums of money, yet few funds are available for source separation or market development. Various government pollution control programs exist to encourage air quality control, but when recyclers apply for credit for diverting waste from landfills or for energy-pollution credit, this is considered "unacceptable."

Existing and potential investment tax credit programs may be critical in terms of secondary market development. A 10 percent tax credit which is significant for a new facility might be insignificant to an existing facility attempting to retrofit (2).

Industries heavily capitalized with virgin material use and equipment may want to amortize equipment prior to converting to recycling technology.

Research Recommendations--

1. Evaluate the applicability of such funding programs as SBA and CPCFA to determine their applicability and usage to the field of glass and plastic recovery/recycling.

2. Evaluate current manufacturing investment trends and determine if there is a potential for incorporating a specific percentage of investment monies for recycled materials production.

3. Assess whether the low costs of virgin material extraction (minus social and environmental costs) have influenced investment decisions. Determine how to include social and environmental costs into estimates.

Technology

It has been shown that technologies for recovering glass and plastics have lagged. Cheap raw materials have offered little to encourage the use of secondary materials. Recent research indicates that:

- Specification of markets is a first priority. The market itself determines the recovery method, to a point.

- If no market exists, there should not be a recovery of products.

- Recovered materials have been traditionally low in price due to low demand.

- There is no point in achieving a level of recycling for either glass or plastic if they are to displace each other. Compatible uses need to be explored.

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- More market research should be conducted.

Glass Objectives

1. Continue research into development of specifications for secondary uses.
2. Continue development of standard sampling procedures for cullet so as to promote quality control from point of collection to ultimate disposition.
3. Investigate decolorizing agents for batches.
4. Investigate application of smaller scale optical color sorting systems.
5. Evaluate the time-temperature relationships and the use of fluxing agents in reducing detrimental effects of refractory particles in recovered cullet.
6. Develop improved techniques for pulverizing for use in secondary products.
7. Determine feasibility of compatible bottle washing-cullet recovery plants.

Plastic Objectives

1. In-depth energy studies should be conducted to determine highest use potential for plastics as an energy source.
2. Investigate the use of markings on plastic products to facilitate the recovery process.
3. Investigate additional cryogenic processing techniques to remove plastics from mixed wastes.
4. Develop a linkage between foreign technologies and the United States state-of-the-art.

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SECTION 3

MANUFACTURING AND INDUSTRIAL BACKGROUND FOR PLASTICS AND GLASS

Coupled in this section are two subsections describing features of both plastics and glass industries. Origins, process descriptions, material production quantities, flows and markets are identified.

PLASTICS MANUFACTURING AND PLASTICS INDUSTRY

Plastics is a generic term describing strong, durable, light, easy to fabricate, fairly inexpensive materials derived from petrochemical feedstock. Plastics are available in over 40 "families" or material types with a broad range of performance characteristics (3). Plastics are a rapidly increasing segment of the economy, and new and variable uses and markets make the industry itself difficult to characterize.

All plastics are either thermosetting or thermoplastic. Thermosetting plastics are set into permanent shape by the application of heat and pressure and on reheating, cannot be reshaped. Thermosets account for over 20 percent of the total U.S. polymer production and are often used for durable goods such as counter tops, pot handles, knobs, highly engineered applications, and do not significantly add to the municipal solid waste stream (3).

Thermoplastics soften upon reheating and harden upon cooling. Ease of use of thermoplastics, plus specific resin characteristics enhance their use. Thermoplastics are often found in the municipal solid waste stream (3). Thermoplastics account for approximately 80 percent of polymer production (4).

Industry Description

Plastics manufacturing is classified by the Standard Industrial Classification (SIC) system under the major group headings of Chemicals. Specifically, the industry classifications are 2821, plastics materials and synthetic resins, and 3079, miscellaneous plastics products. In 1977, SIC 2821 included 430 plants, and SIC 3079 included 3,319 plants (5). Plastics production is actually a part of the U.S. chemical industry.

Plastics manufacturing is a diversified and complex operation. From the raw material input to the final consumer product, the various operations within the plastics industry are integrated into various segments. Figure 1 shows the interrelationship among the various operations involved in the manufacture of plastics (6). Integration of operations within the plastics industry is extensive; thus, one company can be a resin producer,

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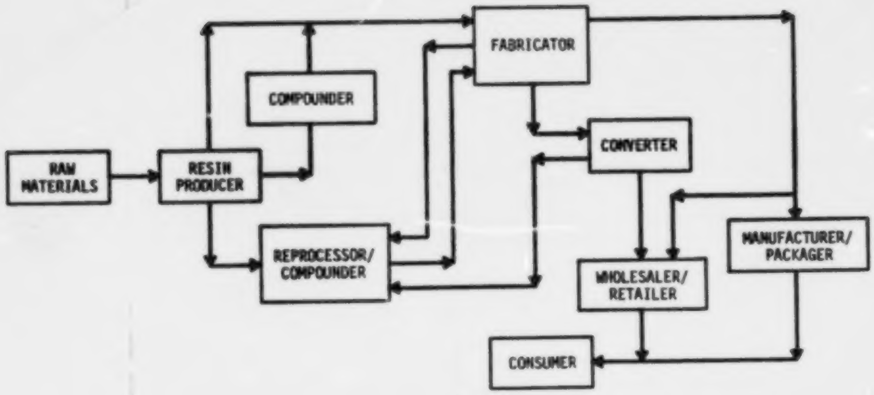

Figure 1. Interrelationships among various operations in the manufacture of plastics.

compounder, and fabricator; and a manufacturer/packager can sometimes operate as fabricator and converter. As a plastic product is made, starting from the resin, it normally passes through manufacturing facilities that progressively become smaller in size, and more dispersed geographically. The wholesaler/retailer and consumer segments are dispersed according to population density and end use markets.

The resin producers convert petroleum raw materials into polymers of various molecular weights which define the chemistry of the plastic item. The resin producer sells his product primarily to the fabricator, although small amounts, usually less than 10 percent, are sold to compounders. Resin producers usually work with fabricators to meet their specific needs.

Compounding is the process of mixing resin with colorants or other additives to enhance desired product properties. Compounding is often carried out immediately after polymerization. Most compounding in the plastics industry is done by fabricators at their own facilities. However, compounding can be carried out by specialists known as compounders and by reprocessors.

Most reprocessors compound and, consequently, the functions of the compounders and reprocessors are similar. The reprocessor/compounder usually uses both scrap plastic and virgin polymers or compounds as raw materials. The reprocessor normally locates relatively close to his customers and is represented by small companies which are geographically concentrated in the major population areas.

Fabricators transform polymers or compounds to a finished or semi-finished plastic product. Several processing methods are used by the fabricator to manufacture the desired plastic product. The various processing techniques used include injection molding, blow molding, compression

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molding, extrusion, thermoforming, transfer molding, reaction injection molding and rotational molding. These various techniques are used to manufacture specific products depending on the customer's particular needs.

Converters transform fabricated items into finished plastic products. Major outlets for the converter's products are the manufacturer/packager and the wholesaler/retailer. Customers are mainly interested in the appearance and performance of the finished goods.

The manufacturer/packager works closely with fabricators. Specifications by the manufacturer/packager are usually set on a performance basis. The manufacturer/packager can distribute his product in three different ways: (1) to the wholesaler; (2) directly to the retailer; (3) to the consumer.

The wholesaler's major function is to purchase products in large quantities from manufacturers, warehouse them, and prepare small, usually mixed, orders of products for shipment to the nearest retail outlets. The retailer also receives his shipment and usually keeps a stock available. An example would be supermarkets which use polyvinyl chloride (PVC) film and foamed polystyrene for meat and produce wrapping in addition to clear polystyrene trays and polyethylene bags.

The consumer is the final point for many of the plastic products. The amount of time the consumer uses a specific product depends on the service life of that product. Table 1 illustrates the average service lives of various plastic products (6). As expected, the service life of such items as packaging, disposables, and photographic film is less than one year, whereas plastics used for construction or electrical equipment have a much longer service life.

History of Plastics

The origin of plastics is found in Biblical references to the use of naturally occurring polymers as fillers, etc. These natural materials were precursors of what now has been termed "plastics". There is no definitive date for the beginning of the plastics industry; however, Table 2 indicates relative dates and uses for which major plastics were introduced (5).

In the United States during the 1860's, John Wesley Hyatt experimented with cellulose nitrate and eventually patented the use of collodion, a cellulose solution in an alcohol-ether mixture, for coating billard balls. His brother, Isaiah, later took out a patent for a process of producing a horn-like material using cellulose nitrate and camphor. The camphor served as a plasticizer for the cellulose nitrate, and he called his product Celluloid.

Another important material in the early history of plastics was formaldehyde. Early efforts resulted in the discovery of casein plastics, produced by reacting casein with formaldehyde. Later, in the early 1900's phenol-formaldehyde became the first commercially successful fully synthetic resin.

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Table 1. SERVICE LIFE OF VARIOUS PLASTIC PRODUCTS

Product	Estimated life (years)
0 - 5 years:	
Packaging	1
Novelties	1
Photographic film	1
Disposables (dinnerware, hospital goods)	1
Construction film	2
Footware	2
Apparel	4
Household goods	5
Toys	5
Jewelry	5
5 - 10 Years:	
Sporting goods (recreation, boats)	7
Automotive	10
Phonograph records	10
Luggage	10
Appliance	10
Furniture	10
Cameras	10
10 to 30 Years:	
Wire and cable	15
Business machines	15
Miscellaneous electrical equipment	15
Hardware	15
Instruments	15
Magnetic tape	15
Construction	25

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TABLE 2. INTRODUCTION OF PLASTICS RESINS

Date	Material	Example
1868	Cellulose nitrate	Eye glass frames
1909	Phenol-formaldehyde	Telephone handset
1919	Casein	Knitting needles
1926	Alkyd	Electrical bases
1927	Cellulose acetate	Tooth brushes
1927	Polyvinyl chloride	Wall covering
1929	Urea-formaldehyde	Lighting fixtures
1935	Ethyl cellulose	Flashlight cases
1936	Acrylic	Brush backs
1936	Polyvinyl acetate	Flash bulb lining
1938	Cellulose acetate butyrate	Packaging
1938	Polystyrene	Housewares
1939	Nylon	Gears
1939	Polyvinylidene chloride	Packaging film
1939	Melamine-formaldehyde	Tableware
1942	Low density polyethylene	Packaging
1943	Fluoropolymers	Industrial gaskets
1943	Silicone	Motor insulation
1945	Cellulose propionate	Pens and pencils
1947	Epoxy	Tools and jigs
1948	Acrylonitrile-butadiene-styrene (ABS)	Luggage
1949	Allylic	Electrical Connectors
1954	Styrene-acrylonitrile (SAN)	Housewares
1954	Polyurethane	Foam cushions
1956	Acetal	Automotive parts
1957	High density polyethylene	Milk bottles
1957	Polypropylene	Safety helmets
1957	Polycarbonate	Appliance parts
1959	Chlorinated polyether	Valves and fittings
1962	Polyallomer	Typewriter cases
1962	Phenoxy	Bottles
1964	Ionomer	Skin packaging
1964	Polyphenylene oxide	Battery cases
1964	Polyimide	Bearings
1964	Ethylene-vinyl acetate	Adhesives and coatings
1965	Parylene	Insulating coatings
1965	Polysulfone	Electrical electronic parts
1970	Thermoplastic polyester	Electrical electronic parts
1973	Polybutylene	Piping
1975	Nitrile barrier resins	Non-food packaging
1977	PET	Beverage containers

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Success of phenolic moldings led to research of reacting other materials, such as urea and thiourea, with formaldehyde. In addition, cellulose acetate was developed about the same time as the urea-based resins.

Plastics play a vital role in every phase of the American way of life. Today there is virtually no product area where plastics do not make a major contribution. Most of the important developments in plastic technology have transpired since 1940. Modern technology is currently permitting the development of new and diversified plastics products.

Initial commercial development of many of today's major thermoplastics began in the period 1930-1940. Due to World War II, synthetic polymers plastics became in great demand, mainly as substitutes for materials in short supply, such as rubber. Large-scale production of synthetic rubbers resulted in extensive research into the chemistry of polymer formation, and eventually, to the development of more plastic materials (6).

Although most processing techniques used in forming and fabrication of plastics are adaptations of techniques used in the metal and ceramics arts, improved resin quality, new polymerization techniques, and better processing technology have significantly contributed to the development of the modern plastics industry. The driving force behind these improvements has been that the demand for plastic products has increased. Likewise, the availability and applications of polymers have been modified by chemical and physical methods of both natural and synthetic products and by synthesis of new macromolecules.

Plastics Production

Most plastics are based on natural or synthetic organic macromolecules in which long chains of atoms are joined by covalent bonds to form a replication of simple groups of atoms. The physical properties of these long chain structures are a function of chain length and the degree of attraction among these chains (4).

Plastics is a general name of the intermediate and final stages of materials that contain polymerized organic substances of large molecular weight. It is solid in its finished state, and at some stage in its manufacturing or processing, the finished articles can be shaped by flow. Common basic raw materials or feedstocks used for plastics are petrochemicals. More than 70 percent of petrochemicals are completely dependent on the molecular structures found in oil and natural gas liquids (5). The remainder of our petrochemicals are currently derived from natural gas or coal.

The actual manufacturing of plastic from the raw feedstock to the final product is very complex and beyond the scope of this report. In general, the feedstock is used to make monomers which are reacted to form polymers. Polymeric materials consist of long-chain, threadlike molecules. The long chains may be branched or crosslinked and may contain more than one monomer species. There is a very definite relationship between molecular structure and end-use properties. Properties of interest include mechanical, chemi-

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cal, thermal, optical, and electrical characteristics. These properties vary according to the desired end-use of the plastic material.

In addition to raw material precursors, additives such as stabilizers, flame retardants, colorants, plasticizers, reinforcing agents, and processing aids are often added to resins to produce plastics that will provide satisfactory service for the proposed end-use. Additives along with the specific resin material tend to make the specific chemical and physical property of a plastic unique during processing. For example, there are over 700 different grades of polyethylene alone (7).

Each intrinsic property of a final plastic product is based on accurate and exact chemical manufacturing techniques. Usually the composition of the starting material is well defined with pure compounds. Any impurities will give the process some difficulty. This aspect is highly critical in the usage of scrap plastic in both regrinding and scrap applications.

Of importance to recycling is that plastics are generally sensitive to environmental conditions and particularly to oxidation. The net effect of reheating or weathering can cause plastics to become embrittled and discolored. Since recycling normally involves reheating, some reduction in qualities is expected. Further, this process of degradation (for purposes of reuse in like products) begins almost immediately upon reheating after cooling. To retard such effects in virgin materials, stabilizers or other additives are often added.

Plastics production data for 1980 are presented in Table 3 (6). The major plastic-types are presented for thermoset as well as thermoplastic groupings. Polyurethane is included under the grouping of all other plastics. The five major groupings of thermoplastics, high and low-density polyethylene, polypropylene, polystyrene, and polyvinyl chloride, account for approximately 55 percent of the total plastics production in 1977. The majority of these thermoplastics are used as plastics for packaging, which account for approximately 25 percent of the total plastics market.

Plastics Packaging

Plastics packaging, the largest and most rapidly growing market for plastics, also represents the use with the shortest service life. While many plastics wares such as furniture, construction materials, housewares, appliances, etc. generally last from 5 to 40 years and do not contribute significantly to municipal waste, packaging generally lasts 1 year. Of the resins produced for packaging in 1979, over 59 percent HD and LD polyethylene, 5 percent was PVC 4 1/2 percent was PET, 7 percent was PP and 16 percent was PS (3). Hence, most discussions related to disposal or the need for recovery are addressed to polyethylene, PET, polypropylene, polystyrene, and PVC which collectively comprise about 85 percent of all plastics in the municipal solid waste stream. Plastics packaging has been estimated to comprise approximately 13.1 percent of the total packaging market (8).

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TABLE 3. TOTAL U.S. PLASTICS PRODUCTION (1980)

Resin type	Production	
	Gg[a]	Million pounds
Epoxy	118	261
Phenolic	662	1,458
Polyester	482	1,061
Urea	437	963
Melamine	91	200
Total selected thermosets	1,790	3,943
ABS	485	1,069
SAN	52	115
HDPE	1,658	3,652
LDPE	2,938	6,471
Nylon	115	254
Polypropylene	1,247	2,747
Polystyrene	1,564	3,446
PVC	2,385	5,253
Total selected theremoplastics	10,441	23,007
All other plastics	3,177	6,998
Total plastic production	15,411	33,948

[a]Gg represents 10^9 grams

GLASS MANUFACTURING AND GLASS INDUSTRY

In order to appreciate the problems involved with the recovery and recycling of glass waste, it is necessary to have some awareness of the nature of the glass industry and the classifications of its products. For example, container glass is considered as being perhaps the most readily recyclable of all packaging materials, yet glass is among the lowest in recovered materials when the reuse of in-plant generated scrap is excluded. Only recently have some of the traditional views of the glass manufacturing industry been modified toward considering the large scale use of glass cullet. In this sense, the entire secondary glass industry, including applications or products, specifications, markets, price history, etc. is in an emerging state and is certainly not as clearly defined as, for example, the well established scrap metals industry.

Glass has the following characteristics: chemically inert, impermeable to all liquids and gases, sanitary and odorless, can be made transparent, and versatile and adaptable in that it can be molded to almost any shape and size (9).

Industry Description

The glass manufacturing industry is classified in accordance with the industry definitions embodied in the Standard Industrial Classification (SIC) system. Under the SIC system, an industry is generally defined as a group of establishments producing a single product or an allied group of products. As of 1980, there were 125 primary glass producing companies which altogether operated 344 individual plants (10). These are defined by SIC coding and quantities below:

SIC CODING	COMMON DESCRIPTION	NUMBER OF PLANTS
3211	Flat Glass	32
3221	Container Glass	123
3229	Pressed and Blown Glass, not elsewhere classified (NEC)	165
3296	Wool Fiberglass	24

Glass manufacturing facilities are located throughout the United States and are usually situated near the markets they serve. Plants are found in 34 states with the majority located in the following 10 states: California, Illinois, Indiana, New Jersey, New York, Ohio, Oklahoma, Pennsylvania, Texas and West Virginia.

Recent production rates and dollar shipments for each segment of the industry are summarized in Table 4 (11).

TABLE 4. 1976 PRODUCTION RATES AND VALUES OF SHIPMENTS

Segment	SIC code	Production rate in 1976*	Annual growth rate percent	Dollar value of shipments in 1976 (millions of dollars)
Flat glass	3211	2.64 Tg (2.91 MM tons)	2.5	1,695[a]
Container glass	3221	11.8 Tg (13.0 MM tons)	3.1	4,350[b]
Pressed and blown	3229	1.77 Tg (1.95 MM tons)	3.5	1,598[c]
Wool fiberglass	3296	0.894 Tg (0.986 MM tons)	7.1	817[d]

*Tg is an abbreviation for 10^{12} grams.
MM tons represents one million tons.
[a] 1978 profile
[b] 1979 profile

The 32 primary flat glass manufacturing plants are located in various regions across the United States. Demand within the flat glass industry is derived primarily from the automative market and the residential and nonresidential new construction market which has had tremendous growth over the past decade. In addition, the secondary construction market (repair and remodeling) provides a major market for flat glass products.

Flat glass production in 1976 was about 2,640 Gg (2,910,000 ton). It is estimated that production in 1978 will be approximately 2,720 Gg (3,000,000 ton) based on an annual growth rate of 1.8 percent (11).

About 70 percent of all containers were produced by 40 container glass manufacturers. In early 1980, 123 container glass plants produced about 12.16 Tg (13.39 MM tons) of container glass (10). The overall industry is also highly concentrated, with the four largest glass companies accounting for 56 percent of product sales. The top eight account for 77 percent of all sales (10).

Glass has been a choice packaging material due to its relative inertness, resealability, and reusability. Container glass demand is derived primarily from two major market segments, food and beverages. Wines, liquors, beer, and soft drinks form the beverage market, while relatively minor markets include toiletries and cosmetics, household and industrial chemicals, and drugs, medicinal, and health products.

Container production is generally divided according to the following percentages: food (31.5%), liquor (4.8%), wine (2.6%), beer (20.2%), soft drinks (26.5%), medical (8.5%), toiletries (4.5%) and chemicals (1.4%). The national average usage is about 250 units per capita per year. During the last decade the consumption of glass containers decreased about 5.2 percent per year on a unit basis to about 2.4 percent (12). Since the majority of glass containers are eventually discarded (even returnable containers only have a refilling expectancy on the order of eight refills), it is not unreasonable to view the entire output of the container industry as ultimately terminating in municipal waste streams. Competitively, glass has not changed in its market share for the last ten years. Table 5 shows the relative status industry-wide versus other packaging materials (8).

TABLE 5. SHARE OF TOTAL PACKAGING MARKET

Packaging Material	Year			
	1961	1970	1976	1980
Paperboard	37.9	34.0	33.5	31.5
Metals	25.0	27.8	27.5	29.2
Plastics	5.3	9.1	12.0	13.1
Paper	15.6	13.7	11.9	11.5
Glass	8.6	9.8	9.8	9.8
Wood	4.5	3.8	3.6	3.5
Textile	2.5	1.5	1.2	1.0

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In the beer market, glass competes with metal cans. Nonreturnable beer bottles account for more than 95 percent of the total beer bottle shipments (11). Plastic bottles are not expected to impact the beer industry market in the near future due to preservative aspects naturally derived from use of colored glass.

Container glass in the soft drink market competes with both metal cans and plastics. The major competitors to container glass in this market are metal cans; however, plastic containers, mainly in the 32-ounce and oversizes, are cost competitive with the glass and metal containers (11). Wine and liquor bottles remain a healthy market. The need for an inert surface, pressureable container, and commercial appeal has negated the use of plastic. However, there is a current movement to appeal the ban on PVC containers for liquor in light of "new evidence "(13).

Smaller-sized plastic bottles are still higher priced relative to a comparable glass product. However, the weight advantage of plastic containers over container glass, coupled with anticipated reduction in production costs, will probably result in a decreased share of the market for glass during the early 1980's (11). There is an attempt to overcome this by increasing the use of plastic sheaths as a mechanism to control explosions in thin walled glass containers.

The food industry continues to be the largest single user of container glass. Glass containers appeal to many customers since it helps to maintain freshness and quality while the container's contents are clearly visible on market shelves, enhancing the aesthetic appeal of the product.

The pressed and blown segment of the glass industry has the largest number of plants (165); however, production is estimated to be only about 1,910 Gg (2,100,000 ton) in 1980 (10). Each plant within this segment manufactures glass and glassware that is used commercially and by household consumers. Consumer glassware includes products such as tumblers, stemware, tableware, cookware, ovenware, kitchenware, and ornamental, decorative and novelty glassware. Commercial glassware includes products for the lighting and electronics industries and various other fields, such as the scientific and technical markets.

The textile fiberglass industry is classified under the pressed and blown glass segment. Major uses of textile fiberglass materials include fiberglass-reinforced plastic, tire cord, and decorative and commercial fabrics. Other less extensive end-uses are electrical wiring and appliances, and paper and tape reinforcement.

Fiberglass-reinforced plastics compete with aluminum and steel in the transportation market. Advantages are: equal strength and durability, opportunity for parts consolidation, resultant savings in cost and energy, and corrosion resistance. The most important advantage is reduction in weight, enabling production of lighter-weight, energy-saving automobiles and trucks. This industry represents the strongest market for glass in the near term.

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Estimated capacity in the textile fiberglass industry in 1977 was 380 Gg (420,000 ton) (11). Annual growth rate is estimated at 9 percent. Thus, 1978 production for comparative purposes is estimated at 420 Gg (458,000 ton). Of this amount, over 80 percent is anticipated to be fiberglass-reinforced plastics (11).

Another improving segment classified under this SIC coding is related to energy. Ford Motor Company, for example, recently received $450,000 from the Federal government to supply 1,000,000 square feet of low-iron glass for solar energy transmittance functions. This glass is to be used on a DOE solar electric plant in Barstow, CA (14).

The final segment of the glass industry is the wool fiberglass industry. Wool fiberglass is used primarily as building insulation and also in acoustical ceiling tiles, heating and cooling pipe and duct insulation, and in process equipment and appliance insulation. The 1979 production rate was estimated to be 1.50 Gg (1,299,500 ton). This represents a 15 percent increase over 1978 (13). Although there are an estimated 3,000-4,000 glass insulators in the U.S., 10 make over 30 percent of products (14). Literature references indicate that this area has potential for increased waste cullet use. This will be discussed later in Section 8.

History of Glass Production

Glass is a natural substance that can be composed of varying elements. Obsidian, a product of volcanic eruptions, is a natural glass formed as a byproduct of superheating and cooling of igneous rock. Glass may be formed as a result of fusion of sand crystals, e.g., quartz, which is composed of silicon oxides. Glass is characterized by an amorphous "crystalline" structure, translucent or highly vitreous surfaces, and conchoidal fracturing. Glass is also highly abrasive.

Glass making is one of the oldest industries. A common natural glass, obsidian, had widespread application in the Stone Age for arrowheads, spearheads, and knives. The glaze used on the stone heads of the Barbarian Age (circa 12,000 B.C.) is the earliest known artificial glass, and the oldest articles made completely of glass are dated about 7,000 B.C. (9).

Glass blowing represented the first true revolution in glass making and was attributed to Phoenicians in 50 B.C. Glass making, though, appeared to thrive mainly in the Mediterranean region until the 12th Century. Venice was considered the great glass producer of the Middle Ages, with artisans creating numerous stained glass works and other sculptures. With these latter uses began the practice of utilizing various metals to achieve various colors or enhance certain properties.

It was not until the mid 19th Century that glass production changed from its artisan origin to a manufacturing process. By the late 1800's, the first glass machines were introduced. In 1903, the Owen's Bottle Maker was introduced which revolutionized society and packaging (15).

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As mass production developed in the United States, so did the packaging industry. The introduction of mass distribution of beverages and the growth of the retail food industry spurred the use of glass as a packaging material. The growth of local industries (e.g., bottle manufacturing, bottlers, and distributors) enhanced the use of returnable bottles. However, increased centralization and marketing efforts stressing the concept of "convenience" to consumers, e.g., the one-way bottle, were initiated in the 1950's. The one-way container eventually replaced, to a large extent, the deposit bottle industry. The one-way bottle was lighter, did not require back haul, reduced retail storage space, and eliminated costly labor. Although more costly to produce per unit, the increased volume, lower transport costs and greater sales provided much higher profits than under the deposit system.

The glass industry is currently undergoing several trends. One is that there are several efforts across the nation to reinstate deposits on beverage containers. Another is that the growth segments of the glass industry have been partly static in traditional areas such as containers (except for beer containers). Also, there have been strong growth trends in fiberglass reinforced plastic, wool, fiberglass insulation and in energy-related manufacturing applications.

Glass Production

The glass manufacturing procedure is usually a fully integrated, one-step process which begins with the raw material and terminates with the finished product at the same location. Basic raw materials involved in glass production, principally sand, soda ash and limestone, are abundant and of relatively low cost.

Glass is manufactured by a high temperature conversion of raw materials into a homogeneous melt (called the batch) capable of fabrication into useful articles. This process can be broken down into three subprocesses: raw material handling and mixing; melting; and forming and finishing. Figure 2 gives a typical flow diagram for manufacture of soda-lime glass (9); however, it has general application to other commercial glass formulations.

The three materials most used in manufacturing glass are glass sand (essentially quartz (S_iO_2)), soda ash (NA_2CO_3), and limestone ($CaCO_3$). These supply the major ingredients found in container and flat glass. Typical raw material batch recipes for several types of glasses are given in Table 6 (11). However, practically every element in the periodic table has been used in the manufacturing of glass. The ultimate choice of the material used often depends on cost, purity, color, and strength. Batch weighing is readily done to an accuracy of one part in 500. This is necessary to control the properties of the glass being made. Various product specifications demand that compositions of the raw materials be known and kept relatively constant.

The common oxides listed in Table 6 can be categorized as formers, fluxes, stabilizers, and colorers. By themselves, formers account for the random three-dimensional atomic structure characteristic of glass. Fluxes

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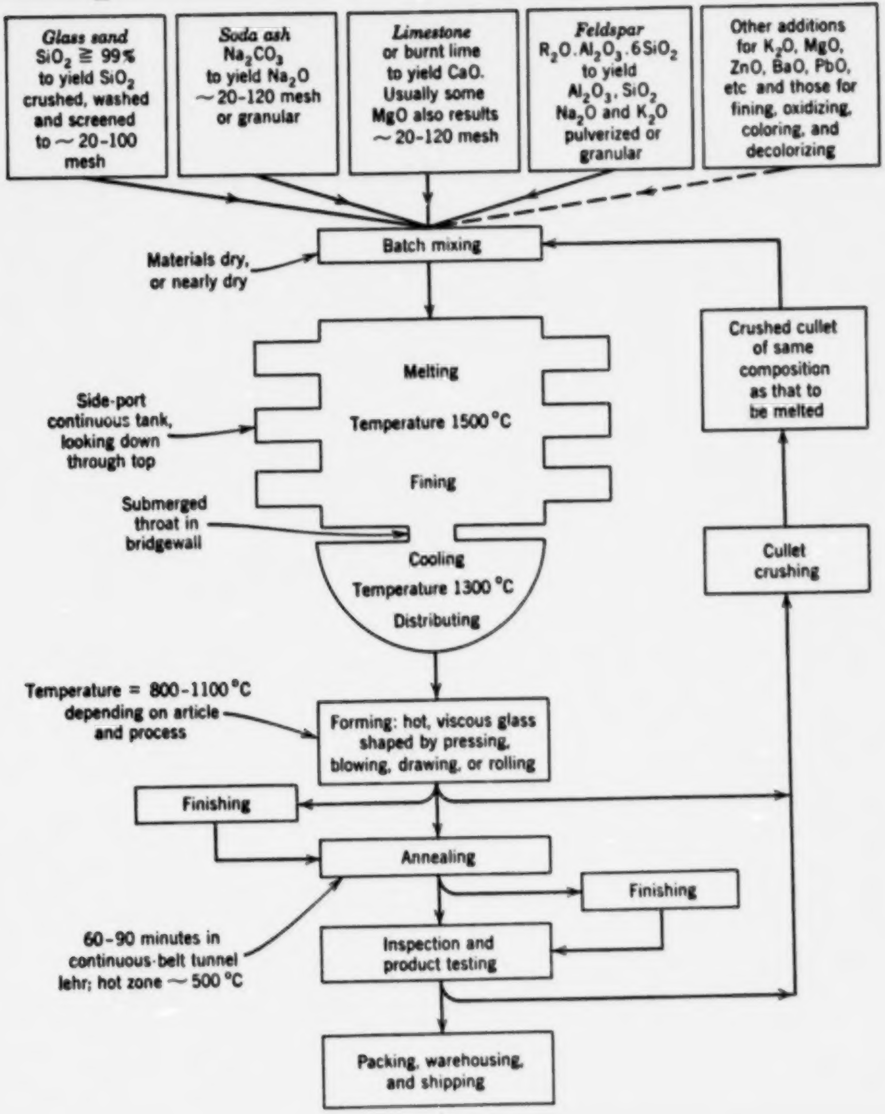
Glass sand
$SiO_2 \geqq 99\%$
to yield SiO_2
crushed, washed and screened to ~ 20-100 mesh
Soda ash
Na_2CO_3
to yield Na_2O
~ 20-120 mesh or granular
Limestone
or burnt lime to yield CaO. Usually some MgO also results
~ 20-120 mesh
Feldspar
$R_2O.Al_2O_3.6SiO_2$
to yield
Al_2O_3, SiO_2
Na_2O and K_2O
pulverized or granular
Other additions for K_2O, MgO, ZnO, BaO, PbO, etc and those for fining, oxidizing, coloring, and decolorizing
Batch mixing
Materials dry, or nearly dry
Melting
Temperature 1500 °C
Fining
Side-port continuous tank, looking down through top
Submerged throat in bridgewall
Cooling
Temperature 1300 °C
Distributing
Crushed cullet of same composition as that to be melted
Cullet crushing
Temperature = 800-1100 °C depending on article and process
Forming: hot, viscous glass shaped by pressing, blowing, drawing, or rolling
Finishing
Annealing
Finishing
60-90 minutes in continuous-belt tunnel lehr; hot zone ~ 500 °C
Inspection and product testing
Packing, warehousing, and shipping

Figure 2. Typical flow diagram for manufacture of soda lime glass.

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TABLE 6. RAW MATERIAL BATCH RECIPES[a]

	Weight in soda-lime container glass, kg (lb)	Weight in soda-lime sheet glass kg (lb)	Weight in borosilicate kg (lb)	Weight in lead crystal kg (lb)
Sand (SiO_2	980 (2,000)	908 (2,000)	908 (2,000)	908 (2,000)
Limestone ($CaCO_3$)	222 (490)	23 (50)		
Dolomite ($CaCO_3oMgCO_3$)		218 (680)		
Soda Ash (Na_2CO_3)	295 (650)			
Potassium Carbonate (K_2CO_3)				132 (290)
Red Lead (Pb_3O_4)				595 (1,310)
Nepheline Syenite (25% Al_2O_3; 15% Na_2O, 60%SiO_2	41 (200)		86 (190)	
Felspar ($K_2OooAl_2Ooo6SiO_2$)		68 (150)		
Anhydrous Borax ($Na_2O..2B_2O_3$			159 (350)	
Boric Acid ($B_2O_3..3H_2O$)			104 (230)	
Sodium Sulfate ($Na_2 SO_4$)	7 (15)	27 (60)		
Sodium Nitrate ($Na_2 SO_4$)	7 (15)		0.2 (0.5)	
Sodium Chloride (NaCl)			0.5 (1)	
Arsenious Oxide (As_2O_3)			0.5 (1)	
Carbon (C)		1 (3)		
Total Weight	1,530 (3,370)	1,554 (3,423)	1,258.2 (2,772.5)	1,635 (3,600)

[a] Weight of materials is based on 908 kg (2,000 pounds) of dry sand.

are added to lower melting points, thus lowering the working temperatures which must be maintained in the furnace. Stabilizers improve the chemical durability of the product glass by lowering the coefficient of expansion and preventing glass crystallization. Of the raw materials listed in Table 6, the borates increase thermal durability of the product glass by lowering the coefficient of expansion, lead increases the refractive index and density, aluminum increases glass strength, feldspar reportedly lowers the mixture melting point and prevents devitrification, sodium accelerates the melting process, and arsenic compounds aid in fining, e.g., removing bubbles from the melt. In addition to these compounds, trace amounts of various metal oxides are added to the batch to change the color of the glass by either imparting a color or neutralizing the tints caused by batch contaminants.

Add-in coloration is itself a product of a number of different trace elements, either imparting color through combination or by colloidal suspension. Typical elements include iron, nickel, cobalt, chromium, copper, manganese, vanadium, titanium, rare earths, gold, silver, cadmium, sulfur, selenium, and tellurium.

Cullet (not shown in Table 6) is the fourth most used ingredient in glass batches; it is the waste glass and rejected ware that is to be remelted. Cullet facilitates melting due to its processed state, but requirements differ depending on type of glass, melting equipment, etc. Usually the total charge has between 10 and 30 percent cullet (16). In some plants where mechanical operations do not produce much cullet, glass tanks are run simply to manufacture cullet for use as a raw material. Cullet handling can be a complicated problem especially in a plant which is melting different compositions, i.e., amber or flint glass. Care must be taken to collect and transport this glass from points where it is produced, to storage sites where segregation by type of glass is necessary to prevent mix up of batches.

Cullet usage in glass manufacturing allows lower furnace temperatures thereby saving energy and increasing the furnace refractory life. In addition, cullet usage reduces atmospheric emissions from the furnace due to lower temperatures and prior removal of emissions from cullet. Thus, there are advantages to the use of cullet. On the other hand, quality control tends to mitigate against extensive usage.

The melt is achieved by mixing of all components in tanks, furnaces, etc. and applying extreme heat normally through combustion of fuel oil, coal, wood, or electricity. Temperatures in the furnace range from 2100F to 2800F. On the average the heat usage in the process results in 6 1/4 - 6 1/2 MM Btu used per ton of glass pulled. Total energy required to melt a ton of glass varies, though, from 2.4 MM Btu hr for all electric furnaces to over 12 MM Btu/hr for direct-fired furnaces. The portion of the energy involved in melting the glass and firing ranges from the electric furnace rate of about 80 percent to direct fired units, 15 percent. The bulk of energy lost is through stack gases, structural loss through conduction, and radiation (17).

Once a homogeneous melt is achieved, the molten glass is extracted from the furnace, shaped to the desired form, and then annealed at a high temperature to ensure quality ware. This final product is either inspected and shipped or sent for further finishing such as tempering or decorating.

Distribution

The flow of glass from primary manufacturer to user/consumer follows traditional lines. Table 7 illustrates typical end uses for glass containers which make up 70 percent of the industry sales. However, the rate at which glass reaches disposal points depends on usage (18).

For example, nonreturnable beverage bottles have a relatively short life and the consumer disposes of this glass as soon as the product is finished. On the other hand, glass used for household windows or television sets is expected to last much longer. Consequently, the life expectancies of the glass products will differ considerably.

Since fiberglasses, both wool and textile, are used primarily for materials with relatively long life expectancies, i.e. building insulation and fiberglass-reinforced plastic, it is anticipated that any contribution to municipal waste centers, the ultimate disposition of wastes, will be in the form of demolition wastes. This waste is usually nonrecoverable.

TABLE 7. GLASS CONTAINERS PERCENT OF END-USES BY WEIGHT

End-use product	Percent by weight
Food	22.2
NR soft drinks	30.9
NR beer	15.5
Liquor	10.5
Wine	8.0
R soft drinks	4.8
Drugs and pharmaceutical	4.9
Toiletry and cosmetics	1.8
Household and industrial	0.9
R Beer	0.5

NR - Nonreturnable
R - Returnable

Likewise, flat glass and some specialty glassware have relatively long life-expectancies and will eventually end up in the municipal solid waste stream at a much slower pace than would be expected for container glass.

Considering the relative life expectancies for the various glass products, and that over 90 percent of glass production is soda-lime glass (essentially of same composition as container glass), the major constituent of municipal solid waste can be assumed to be container-type glass. This assumption is supported by data indicating that 92.6 percent of the total glass waste generated in 1972 was container glass (18). Recent data indicate that this has not changed appreciably.

SECTION 4

STATE-OF-THE-ART FOR PLASTICS RESOURCE RECOVERY

Due to the tremendous growth in the use of polymers or plastics for short-term packaging, increasing attention has been focused on its recovery. However, the recovery of plastics from municipal refuse within the United States is basically embryonic. Currently only specific plastics which are uncontaminated and segregated from other polymers and wastes have potential for recovery. PET bottles, PVC scrap, polyethylene containers, and HDPE film are currently sporadically recovered for recycling. Energy values derived from combustion in energy recovery plants represent the most prevalent form of "recycling".

A less familiar but equally important area is that of "pre-consumer" wastes, those generated by producers, processors and fabricators of products. While recovery of plastics from municipal refuse is not extensive, industrial, and to a certain extent, commercial recovery is quite extensive. Essentially, scrap recovery has long ceased to be an afterthought in most plastics processing operations. Scrap handling has the potential of being as important a plastics processing operation in its own right as processing virgin polymers, since the rising costs of feedstocks makes even small losses significant. There are fewer and fewer operations that cannot justify either regrinding equipment or recovery of off-spec resin for sale (19).

In the following section, methods of recovery are reviewed. Examples are presented of methods that have been used at industrial, commercial and municipal levels. In some cases, identified programs have ceased. Reasons for their failures will be detailed when information is available. Additionally, sources and quantities of plastic wastes will be identified and quantified.

SOURCE IDENTIFICATION AND QUANTITIES

Plastic waste is generated from industrial-manufacturer, commercial and municipal sources. The amount of plastic wastes generated in 1977 and projected for the years 1980-1990, is presented in Table 8 and was scaled from 1974 data. For wastes as received at landfills, the breakdown by source is 84 percent for households, 10 percent for commercial/institutional and 6 percent for industrial. Figure 3 shows a materials flow chart for plastic waste generation (21).

As a fraction of the municipal waste stream, plastics represent a small portion of approximately 4 to 5 percent (22). Plastics as a component of municipal refuse has grown from 2 to 3 percent in the last decade. Unless other materials are extensively recovered, thereby changing the waste stream

TABLE 8. ESTIMATES AND FORECASTS OF PLASTICS WASTES GENERATED AND RECOVERED

Category	Quantity by year (million tons and Gg)[a,b]							
	1977		1980		1985		1990	
	MT	Gg	MT	Gg	MT	Gg	MT	Gg
Total solid waste	140	127	160	145	180	163	200	181
Municipal generation	6.9	6.3	8.4	7.6	11.2	10.1	13.4	12.1
Commercial generation	0.8	0.7	0.9	0.8	1.2	1.1	1.4	1.3
Industrial generation	0.6	0.5	0.7	0.6	1.0	.9	1.2	1.1
Recovery[c]	1.4	1.2	1.6	1.4	2.4[d]	2.7	2.8[d]	2.5
Total waste as generated	6.9	6.3	8.4	7.6	11.0	9.9	13.2	11.9
Percent plastic in mixed wastes	4.9	4.9	5.3	5.3	6.2	6.2	6.6	6.6
Plastics recovery as a % of plastic wastes (municipal) for energy recovery	0	0	4.2	4.2	13.4	13.4	24.3	24.3
Total wastes as disposed	6.9	6.3	8.0	7.2	9.6	8.7	10.0	9.0

[a] - Assume no variation in industrial-municipal, commercial ratios of generation
[b] - Composite of Midwest Researcn Institute and PES estimates.
[c] - Recovery is composite of source separation and energy recovery.
[d] - Incorporates PET recycling at 25 percent efficiency.

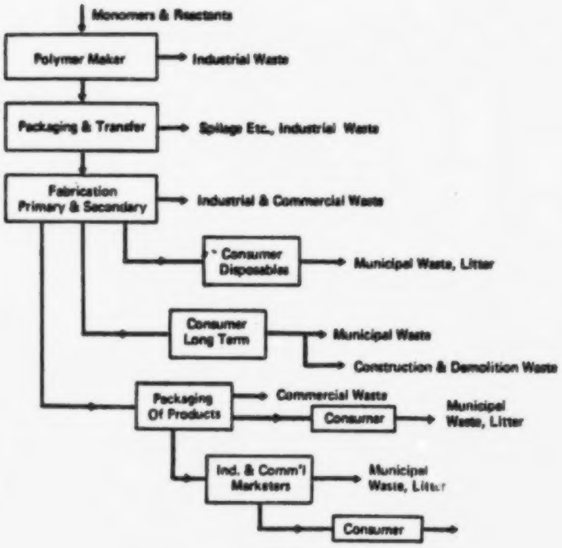

Figure 3. Plastics industry solid waste generation.

composition, this percentage is expected not to increase beyond 6.6 percent in the future (6).

INDUSTRIAL SOURCE RECOVERY

Five different sources contribute to the industrial plastic waste stream. These sources are the resin producer, compounder, reprocessor, fabricator and converter (23). The recycling efficiency of each source, based on throughput, is shown in Table 9 (23).

Table 9. RECYCLING EFFICIENCIES

Source	Recycling efficiency (%)
Resin producer	98.8
Fabricator	98.3
Compounding/reprocessing	99.4
Converting	98.8

Recycling efficiencies are somewhat dependent on the amount of composites manufactured. Industrial wastes are generated as the result of numerous causes including failure to meet specifications of end users, product spills, carryover of product into effluent process streams, and chemical instabilities (19). Additionally, the amounts of waste generated are not necessarily correlated with the plastic resin but with its application. Critical applications such as wire and cable insulation have lower recycling efficiencies than noncritical applications.

Resin Producers

Resin producers convert petroleum raw materials into monomers which are used as a feedstock for conversion into polymers and compounds. Plastic wastes can be generated during many of the operations common to the resin producer including polymerization, additive addition mixing and compounding, pelatizing, preparation of resin for shipment, and storage. Plastic wastes are classified as either recyclable or nonrecyclable. Recyclables may be in the form of off-grade resin, hence it may be used in another fabrication process different from original purposes (6). Plastic scrap may be also suitable for regrinding and combining with virgin resin in fabrication. This reprocessed plastic is commonly called secondary resin (24). About 50 percent of this scrap is sold to a reprocessor; the remainder is sold as a lower-quality resin to a fabricator (23).

Some plastic waste cannot be sold as off-grade and secondary resins or may not be suitable for reintroduction into the fabrication process. These plastics are usually discarded because of contamination, chemical instability, or other problems (such as being a composite). One source has labeled these as "nuisance" plastics as opposed to scrap plastics which are recyclable (6).

Compounders

Compounding is often carried out immediately after the polymerization operation. Scrap plastic generated during compounding is usually recycled in the compounder's facilities rather than sold to an outside reprocessor. Plastic waste material includes those scraps in the form of stands, drippings, and chunks which cannot be recycled because it is severely contaminated. The opportunities for recycling scraps can be limited at times because the compounding operations are usually small (6).

Reprocessors

Reprocessing is often an integral part of fabrication. An average of 10 percent of the resin used in fabrication is recycled, and literature has documented uses up to 40 percent (6). Reprocessing, though, can also be conducted by a special segment of the industry - the reprocessor.

The reprocessor usually uses scrap plastic and/or virgin polymer together with other compounds as raw material. Most scrap plastic used by the reprocessor comes from the resin producer; a small portion comes from the fabricator, and an even smaller amount from the converter.

One of the major functions of the reprocessor is to remove contaminants from scrap plastic. There are a number of different types of operations to accomplish this. Improved characteristics are sometimes only achievable with the introduction of plasticizers. Recent research, though, indicated that reprocessing using glass fibers might enhance degraded resin properties (20).

Fabricator

The fabricator transforms polymer or compound to a finished or semi-finished plastic article. The amount of plastic waste generated depends primarily on the volume of resin used in the particular fabrication process. Injection molding, wire and cable coating, film extrusion, extrusion coating and articles made from foam plastic are the major fabricating processes that incorporate extensive recycling. Recycling by the fabricator ranges from 10 - 15 percent of production (6). Where specifications are stringent, as in PVC bottle production for food application, most of the scrap produced will be sold to other fabricators for use in nonfood applications, and only about 5 percent will be discarded.

Converter

The converter transforms a fabricated item to a finished product such as plastic film bags from rolls of extruded film. Converting operations can generate very large volumes of scraps and plastic wastes. If the converting operation is accomplished in line or adjacent to the related fabrication process, much of the scrap plastic can be salvaged by being recycled in the fabrication operation (6). Normally, the converter can recycle only to a very limited extent due to the products generated (19).

Industrial Recovery Systems

The plastics industry already reclaims and recycles much of its reusable polymer scrap either into the same product lines or into less critical product lines. In the industry, recyclable grades of resin include reusable scrap which is usually reground and reintroduced and offgrade resins and salable scrap.

In industrial operations, scrap recovery simply consists of granulators that grind plastic scrap into fragments of roughly homogeneous size. Although many different designs exist, all contain a set of knives on a rotor that mesh with stationary bed knives. Plastic is thus sliced until it is able to pass through the mesh-sized screen into a collecting bin (19).

Simple granulators are designed for manual feeding, collection and recycling of ground material. However, any degree of mechanization can be achieved, including direct feed of sprues, pinch offsets from custom injection molding, extrusion blow molding, and thermo-forming operations (19).

There are larger operations in which pelletizes-dicers are added to size reduction processes. Where additional compounding is involved in scrap reuse, a melt extruder is used to produce a strand or sheet from which the compound is cut.

Differentiation between equipment is focused on knife design (new angled cutter knives), throat design, auger-fired, automation and operations that regrind prior to cooling of plastics (not-melt granulators) (19).

In angled cutting, knives cut scrap in a slicing action in a nip that progresses along the length of the blade as rotor knives pass the bed knives. Figures 4 and 5 present schematic and dimensional views of this method (19).

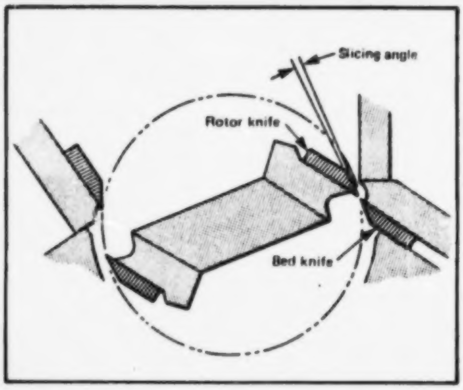

Figure 4. Knife geometry of slicer design.

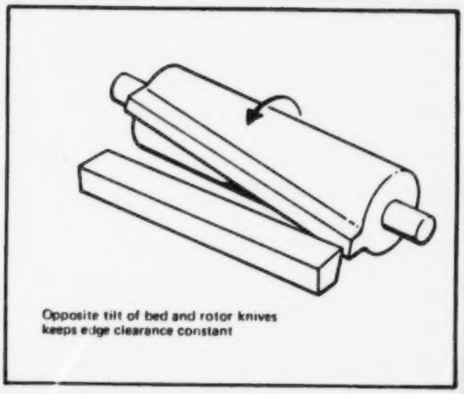
Opposite tilt of bed and rotor knives keeps edge clearance constant

Figure 5. Oppositely tilted rotor and bed knives.

In throat designs, most granulators are fed from the top with materials dropping directly onto the blades. A new model feeds materials from the sides which minimizes "fly-back" from materials (19).

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A particular problem with auger feeding systems has been jamming. As hot "sprunes and runners" fall into an auger, they may wrap around the central shaft. Continued accumulation will eventually block the feeding system. To avoid "clogging", a separate rotor overlaps the auger flight to snag scrap tangled on the shaft. The separate rotor may most likely be the cutting blades (19).

Although not a new concept, hot melt granulators are experiencing renewed interest in the granulating of especially thick purgings generated in, for example, vinyl extrusion operations. Vinyl degrades before cooling, hence it must be ground hot if the scrap is to be reusable (19). In the operation, cut fragments are normally immediately cooled and hardened.

Hot melt grinders are also used in blow molding to recover hot, thick pinch-off scrap prior to cooling and hardening. This grinding of scrap while still hot speeds up the scrap recovery process.

Problems Affecting the Recycling of Plastic Wastes in Industry--

The separation of mixed plastics is one deterrent that industry faces in their efforts to improve their recycling efficiency. This type of problem is experienced in industrial segments such as converters who coextrude and coat plastic film. The scrap that is generated contains mixtures which have generally poor physical properties if recycled into composites. One technique to overcome this is to introduce an additive to improve adhesion between the polymer phases. Another approach to recycling mixed plastic is to mix the recycled plastic blend with nonplastic materials or "fillers". The usual nonplastic materials used with the scrap plastic are paper, wood, glass, organics, metal, or even stone.

Another problem concerns prices. As the costs of polymer production have decreased, the scrap market has become much more selective in the types of polymers selected for reuse (6).

COMMERCIAL SOURCE RECOVERY

The commercial segment of the plastic industry usually receives completely finished articles. This segment, therefore, generates plastic waste in product form rather than the process form generated by industry. The amount of plastic waste generated by assembling and packaging of plastic products varies considerably with the type of product and the company. In contrast to the wastes produced by industry, the commercial wastes are usually contaminated with quantities of nonplastic items such as paper and metal (5).

The manufacturing of plastic goods by the commercial segment can be divided into three use categories; short, intermediate and long-term. Approximately one-third of the plastic products produced went into short-term uses (packaging, foil, bottles, bags, etc.) The remainder of the plastics went into intermediate term uses (clothing, toys, garbage cans, etc.) or long-term uses (cable insulation, piping, appliances, machine parts).

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Most often, heterogeneous scrap recovery is practiced in plants with large amounts of scrap. Typically, automotive and appliance industries are installing or testing equipment and techniques capable of separating and recovering components of plastic-nonplastic composites. A few past and present efforts are presented here to illustrate the variety of approaches. Typical processes used are cryogenics, magnetics, electrostatic separation coupled with air classification, heavy-medium separation, and selective solvent extraction.

Western Electric Company

In-plant reclamation of ABS was accomplished in Western Electric's Indianapolis plant. Approximately 2,040 Mg (2,250 ton) of this virgin material was reclaimed annually. The ABS material was used in injection molding to produce telephone components. Sprues, runners and defective parts were dropped down a chute into 0.45 Mg (0.5 ton) corrugated containers where they were stored until the need arose for a particular material. Then the material was placed on sorting and conveying lines which fed into a modified granulator. Clean ABS regrind from the granulator was fed into an injector molding machine hopper. Regrind containing contaminates was directed into an extruder and then pelletized (25-29).

Nassau Recycle Corp.

NRC, a subsidiary of Western Electric, is in the process of constructing a 15 million lb per year reclamation plant in Gaston, S.C. for the recovery of PVC wire and cable scrap. To date, NRC has recovered 60,000 lbs of PVC scrap which has its origins in applications as old as 25 years. The reclamation is aided by the increasing value of the copper wire (27).

The key mechanism used is an electrostatic separator. First the wire scrap is sorted, chopped, and then granulated. Then an "air vortex aspirator" is used to blow the textile fluff away from the plastic insulation and wire. Then the electrostatic separator, a drum-shaped device, removes the copper wire. An electrostatic charge causes the PVC to cling to the drum. The remaining 2-3 percent of contamination is removed in an extrusion operation using a special automatic screen-changer. The reclaimed PVC is then recompounded with appropriate additives for fire retardance and low temperature flexibility. Major application is expected to be cable jacketing for non-visible uses (27).

Ford Motor Company

Ford Motor Co. has initiated a cryogenic-type operation for recovering ABS from metal plating. Now in use at Ford's Saline, Michigan molding plant, the process is conducted in two steps.

First, the plated parts (scrap bumpers and chrome plated grilles) are broken up into smaller fragments in a conventional 1000 HP scrap grinder. An impact pulverizer then reduces plastic to powder and separates plastic from metal plating.

The key step in this process is to chill the plastic with liquid nitrogen between the grinder and the pulverizer. The cryogenic temperature (-250F) creates high shear stress between plastic and metal due to large differences in coefficients of thermal expansion for each material. This causes the metal to delaminate from the plastic, and the low temperature also makes the plastic extremely brittle, thereby improving the pulverizing action (28).

The second step involves subjecting the mixture to a magnetic field which separates the metal from the plastic. The plastic is remelted, pelletized and eventually used in a molding operation. The metal-plastic separation is more than 99 percent effective (28).

Sears-Roebuck

Polypropylene auto batteries returned as trade-ins to Sears-Roebuck have been recycled. Returned cases are washed and shredded into 1/8 inch particles. These particles are extruded into foam I-beams 2 1/4 - 2 3/4 inches (57.2 - 57.8 mm). The scrap is used at .08 g/cc structural foam density achieved by inclusion of chemical foaming agents. Five product manufacturing lines are in operation throughout the United States (29).

Summary

These programs are representative. Table 10 presents a more complete listing of past and current efforts in the commercial sector.

MUNICIPAL SOURCE RECOVERY

Many sources contribute to the plastics fraction of municipal solid wastes. Institutions including schools, government bureaus, service centers and hospitals; retailers, such as restaurants, department stores and warehouses; and households comprise the significant sources.

State-of-the-art for plastic waste recovery from post-consumer mixed municipal wastes is limited to energy recovery or tertiary recycling, collection and recovery of PET bottles, use of solvents to extract selected plastics, and a few experimental processes to separate plastics from other wastes developed by research entities. The latter will be covered in depth under the research section.

Energy Recovery

Energy recovery as a method of recovery is in no way conducted solely for plastics. Rather, plastics are valuable constitutents of the solid

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TABLE 10. PAST AND PRESENT RECOVERY FACILITIES AND RECOVERY PROGRAMS AT MANUFACTURING OPERATIONS

Agency	Program
1. Cement and Concrete Research Institute	1. Ground plastic as sound replacement.
2. Chem Tac Specialties	2. Grinds rigid plastics for dissolving.
3. Chrysler Corporation	3. Sheds vinyl fabric and urethane foam scrap, impregnates the scrap with vinyl resin, and molds it into automobile mats
4. Cryogenic Recycling Int'l, Inc.	4. Freezes scrap to brittleness, then fine grind.
5. D.M. Fay	5. Explored possibilities of damage from plastic scrap.
6. Dow Altadena	6. Reground high density polyethylene to title, flower pots, etc.
7. Ford Motor Company	7. Recovers ABS
8. Free-Flow Packaging Corporation	8. Collects foamed polystyrene packaging materials from industrial users and recycles it so that it can be re-used in packaging operations.
9. Gold Plastics Services	9. Reprocesses polyethylene bottles to pipes.
10. Gulf Oil Company	10. Incorporates scrap polyethylene into the production of trash bags.
11. Hafner Industries	11. Uses selective solution to recover any plastic scraps.
12. Hoffer Plastics	12. Uses polyethylene scrap in plastic concrete composites.
13. Mobil Plastics Division	13. Recycles foam polystyene egg cartons.
14. Packaging Industries	14. Converts film scrap to extrudables.
15. Phillips Petroleum Company	15. Producing items such as planters from recycled mixtures of plastics.
16. Polymer Recovery Corporation	16. Recovers polyvinyl chloride from a fellow substate.
17. Upjohn Company	17. Converts rigid polyurethane to polyols.
18. Western Foam Packaging, Inc.	18. Recycles foamed polystyrene trays.
19. Poly II	19. Polyesters into many different products.
20. Recycle Unlimited	20. LDPE and HDPE
21. Nu	21. PVC scrap
22. Sears-Roebuck	22. Polypropylene

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waste to be burnt or rendered into fuel. The processes which can or are being used include:

- pyrolysis
- large-scale incineration with heat recovery
- modular incineration with heat recovery
- all forms of refuse-derived fuel

Pyrolysis--

Pyrolysis is an emerging technology whereby organic materials are heated in the absence or near absence of oxygen in a controlled combustion chamber. Pyrolysis is sometimes referred to as destructive distillation because while it drives off volatile components, it does leave a substance consisting mainly of carbon and quite often a fairly large ash content. Products of pyrolysis of thermoplastics include wax-like solids, greases, or liquids. Further cracking of the plastic material yields gases for use as fuel.

Large and Modular Scale Incineration--

Most plastics have high calorific values ranging from 22 to 42 kJ/g (9,500 to 19,000 Btu/lb) (30). Steam generating incineration is one way of recycling the plastics contained in solid waste into a usable form of energy. Steam generating incinerators consist of the conventional municipal incinerator with add-on heat exchange systems or boilers. The waste heat boilers for these systems are located in a refractory furnace, or a water-walled furnace for better heat-transfer efficiency. The generation of electricity from mixed municipal refuse is accomplished by (1) producing high pressure/temperature steam through heat exchange from the waste heat from the combustion process, and then using steam to power a turbine, or (2) using the waste combustion gases directly to power a gas turbine. Steam may also be directly used. Low pressure steam may be used in space heating and to operate "chillers" for space cooling.

There are several energy recovery facilities either under construction, planning or shakedown within the U.S. today. The most successful is operated at Saugus, MA with a reported throughput of 45 Mg/hr (50 tons/hr) (31).

Small-scale incinerators with heat recovery are operated throughout the U.S. Modular incinerator units operate from 4.5 to 45 Mg/day (5 to 50 tons/day). Optimal levels are described at 45 Mg/day. Modular units may be coupled with other units (2 or more) at one plant site to allow larger volumes of processing. These plants range up to 225 Mg/day (250 tons/day). Successful generators are operating at Blythville, Arkansas, North Little Rock, Arkansas and other locations (32).

Auxiliary Fuel Production or Refuse Derived Fuel (RDF)--

The conversion of refuse to provide various forms of combustible products is another way to recover the energy value of plastics from the municipal waste stream. Auxiliary fuel production begins with one or more shredding operations followed by magnetic separation, and finally air classification for removal of a high percentage of the noncombustible fraction (33). RDF may be fluff, pelletized, or densified, depending on burn characteristics desired, and storage and transportation constraints.

In most operations, the actual fuel processing commences with the air classification step. Heavy materials normally composed of noncombustibles are segregated from lights or usually combustibles. Further removal of contaminants involves the passing of the material through tunnels or drying the material from an average 25 to 30 percent moisture content to 5 to 10 percent (25). The product fuel called refuse-derived fuel (RDF) is usually burned as a fuel supplement in conventional boilers. In this process, the RDF is mixed with coal or oil in a furnace to provide the added fuel benefit. Approximately 10 to 20 percent of the fuel mixture can be composed of refuse.

Source Separation

Source-separate collection of plastic waste is limited at present. Both past and present efforts have included collection by recycling centers, and plastics dealers. Reuse programs which have consumers return PET bottles to reclaim deposits have been instrumental in encouraging industry to reuse PET.

Recycled Unlimited (RU), Michigan--

This community group has collected low and high density polyethylene (LDPE and HDPE) (34). RU formerly collected LDPE from department stores primarily, and contaminants were removed by hand sorting. Plastic was sold as feedstock for $0.10/lb. There is high usage of such plastics when it is cleaned and sorted. The material is normally baled. This process is no longer carried out due to the high cost of decontaminating the plastic.

HDPE is currently collected or dropped off by patrons. A commercial granulator grinds the plastic into flakes. Plastic after grinding is stored in 1.2 x 1.2 x 1.2 m (4 x 4 x 4 ft) boxes and shipped by truck in quantities of 20-30 boxes to a processor or market middleman. RU would like to market the material directly, but currently no such buyer exists. RU goes through a "jobber", but some are unreliable (34).

Poly II Process--

A recovery process utilizing some solvent to extract selected plastics is conducted in Los Angeles, California. The process, considered propietary, primarily produces polyester resin for use in approximately 29 different products.

The operation, according to its inventor, will accept PET and other plastics including LDPE, HDPE, PP, and PVC in both mixed and segregated condition. "Poly II" will pick up large amounts and pays up to $0.33/lb. Mixed plastics are "refined" utilizing their patented "Poly II" process. The only specification is that the product be "halfway clean."

The throughput of this operation is rated at 18 to 27 Mg (20 to 30 tons) per hour. No economic data were available. An energy savings of 90 percent over production of similar products from virgin stock is claimed. Environmental emissions, in the form of esters of polystyrene, have been reported as reduced by 50 percent over other solvent operations.

"Poly II" includes, as an integral part of the process, a built-in factor to ease future recyclability, e.g., few composites are produced. This operation does not sell plastics to other dealers but produces the following materials/products on site:

- roofing materials
- solar collectors
- caulking
- nail polish
- paint extenders
- energy monitors
- marble-plastic sinks
- 21 other products

Polyester-polyethylene Terephthalate (PET) Bottles--

Recovery and recycling of post-consumer (municipal level) PET is established and growing. Prompted by bottle deposit laws, anti-litter movements and the need to conserve costly raw materials, recycling of PET is regarded as fully commercial. Both DuPont Co., Delaware and Goodyear Tire and Rubber Co., Ohio, have started up pilot plants for recycling. (The actual mechanics of the recycling operation and marketing of products is covered under markets later in this subsection. Only the actual collection dynamics are identified here.) Industry estimates that PET recycled in 1979 amounted to approximately 3,499,090 kg (3,849 tons). This is estimated to almost double in 1980 (35).

DuPont--DuPont, through its Material Reclamation System (MRS) operated primarily in the southeastern U.S., recycles PET. Ground PET bottles are purchased from bottlers and bottle manufacturers. The ground material consists of polyethylene, aluminum from caps, and paper and glue from labels. The recycling centers segregate these by a propietary method (36).

Goodyear Co.--Goodyear as a major supplier of polyester (PET) has been involved in PET recycling for over two years. They have now developed a PET recycling operation. Goodyear collects PET and densifies it to reduce bulk. Compaction or grinding is utilized for densification. The densified PET is then transported to Goodyear's recycling plant (37). (The operation is detailed under markets).

Owens-Illinois--OI has published a guide to PET recycling which gives urgent attention to the recovery of PET in markets which have container deposit systems. In this guide, bottle fillers are recommended to include a reclamation system. Most bottling facilities can accomodate the necessary equipment. The major component is the granulator. It grinds all materials into scrap particles. Accessories to the granulator include variable feed hoppers, conveyers, air evacuation systems, and scrap shipping gaylords. A minimum of 400 square feet is required for the processing system, with additional space needed for transfer and storage operations (38).

Reclaimers are interested in high volume usage and purchase truck load quantities (22 to 24 gayloads, which are 16 cubic feet fiberboard containers). An average purchase price for PET is estimated at $0.03 per lb. Figure 6 presents a schematic of the reclamation system shown in the guide. It is also noted here that there are several approaches to preparing materials for secondary use. This method and compaction are representative.

Summary

In municipal resource recovery, source separate collection of PET, solvent extraction, and energy recovery constitute the limited state-of-the-art.

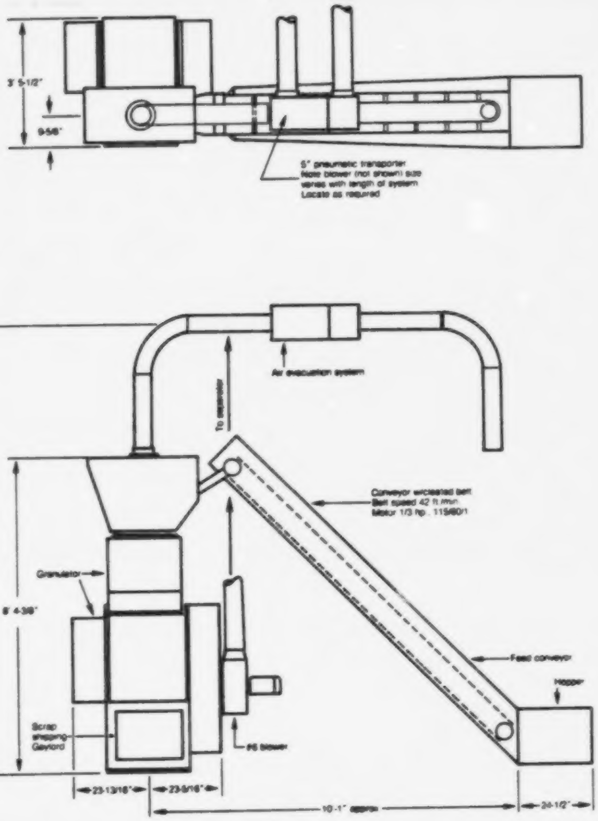

Figure 6. Schematic of PET recovery process.

Markets for Recovered Products

Markets for plastics recovered from municipal refuse is limited. Most polymers except for PET, HDPE, LDPE, PVC and PP will not find markets for reuse. Therefore, this section will cover the markets for these above-named materials where available.

PET--

Recycled PET currently finds its largest end use in strapping and fiber fill; insulation for winter clothing, carpet backing, thermoform sheeting for clear packaging. As of February 1979, the following PET recyclers were documented in literature (35):

Building Components, Inc. or
Recovery Systems
7100 Decelis Place
Van Nuys, CA 91406
Attn: Clyde Berkus

E.I. DuPont de Nemours & Co., Inc.
Materials Reclamation Systems
Wilmington, DE 19898
(302) 772-5265
Attn: R.H. Sharp

Midland Processing, Inc.
2 Quaker Road
Pomona, NY 10970
(914) 354-0300
Attn: Justin Kratter, President

Plastic Recyclers
P.O. Box 1009
Richmond, CA 94802
(415) 235-0295
Attn: Jerry Waylett
Joseph B. Nusbaum

Plastic Recycling Incorporated
12036 Corporate Drive
Dallas, TX 75228
(214) 681-0409
Attn: Kurt H. Ruppman, President

Plastics Development Corporation
704 Traction Street
Los Angeles, CA 90013
(213) 626-8757
Attn: Milton Altenberg

St. Jude Polymer Corporation
39 N. Main Street
Mahonoy City, PA 17948
(717) 773-0368
Attn: Steve Babinchak

Three M - 3M
3 M Center
St. Paul, MI 55101
(612) 733-9510
Attn: Judd Hawthorne

Willman Industries, Inc.
Route 41
Johnsonville, SC 29555
(803) 386-2011
Attn: Greg Willman

Pure Tech Industries, Inc.
4 Barnet Road
Pinebrook, NJ 07058
(201) 227-1000
Attn: Frank Tammera

Ralco Industries, Inc.
Manville Hill Road
Cumberland, RI 02864
(401) 767-2700
Attn: Robert A. Lebeau, President

Using the Goodyear Tire and Rubber Co. as an example, the actual mechanics of recycling will be described. Economics are detailed in Section 6, Economic and Environmental Impacts.

Goodyear Tire and Rubber Co.--The process description for the Goodyear program is summarized in Figure 7. The objective of the system is to process the mixed materials into a usable form of polyester. It is noted that the eddy current separator is not commercially used nor is the washing step. System capacity is rated at 50 lb/hr (mg/hr) (37).

Densified material is ground to a particle size of 1/2 inch (12.7 mm). This reduces the materials to a discrete size for later separation techniques. The techniques must effectively distinquish between polyester and nonpolyester material based on properties of density, conductivity, surface tension, and particle shape and size.

Following magnetic separation, a routine recovery step, paper labels must be removed. This is accomplished by a unique fluidized bed separator. Material is agitated while low pressure fluidizing air is directed upwards through the mixture. The material is stratified by density with the light material, a small percentage, removed by an exhaust fan. The heavy fraction is gravity fed to an eddy-current separator where aluminum and other nonferrous metals are separated.

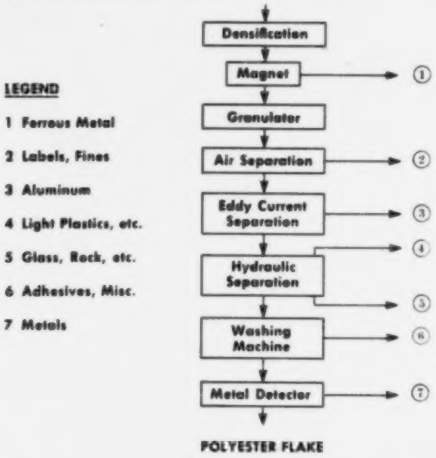

Figure 7. Post consumer PET recycling

The eddy current separation relies on the induction of electrical currents in the metal particles where they are exposed to a variable magnetic field. The interaction of currents and the field deflect these materials out of the stream containing nonmetal materials.

The process stream is then conveyed to hydraulic separators where material of different density than polyester is separated. A nonionic surfactant is added to lower the surface tension of water to slightly less than the PET's of 43.5 dynes/cm. Glass, rocks, adhesives, etc. are thusly removed in sink/float chambers.

After sink-float, washing machines remove traces of non-PET plastic and papers. The product stream is dried and passed through a metal detector to insure metal contaminants were removed.

This PET is suitable for nonfood applications and contains less than 0.2 percent impurities, but has a variable color due to green and clear bottles as well as the impurities.

Markets for Plastics--

Polypropylene is collected by Ecolo-Haul in Los Angeles, CA in battery case form at $0.03 per battery (40). A company in Canada, Tonelli of North America, is currently considering constructing a plant in Los Angeles, California for purchase and recovery of polypropylene from battery cases. Also, Sears-Roebuck recycles returned cases in five U.S. cities (29):

- Elk Grove, IL
- Philadelphia, PA
- Misquette, TX
- Atlanta, GA
- Los Angeles, CA

Polyethylene is purchased by Poly II process in Los Angeles at about $.10/lb. Recycle Unlimited purchases high density PE at about the same price in Michigan.

Market constraints--The market constraints continue to be the lack of large amounts of clean segregated scrap, and as a result, a poorly defined and stable secondary plastic materials industry. Many products made from recycled plastic still have to be marketed, and consumers are not usually aware of products that do contain recycled plastics (from MSW).

The low price per pound of virgin polymer also acts as a constraint. With secondary resin markets already fully utilized, there is no room economically for scrap recovered from municipal waste due to the high amounts of impurities and the degree of difficulty involved in segregation of polymers.

FUTURE TREND IN PLASTICS RECOVERY FROM MUNICIPAL WASTE

Plastic recovery from municipal waste is currently limited. Although litter problems and energy and resource material shortages have spurred great interest in plastics recovery, technological problems and marketing constraints severely hamper the growth of a recycling industry. There is little financial incentive on the part of consumers to segregate plastics even when markets are nearby.

However, several trends have been identified from both conversations and literature surveyed in this document:

- More emphasis on fiberglass plastic reinforcement products may trigger increased recycling.
- Long term use of composites (especially insulation) where specifications for resins are relaxed has been an area of interest.
- Bottle reuse programs enhance the feasibility of plastics recycling for specific polymers (PET for example). A clean, segregated scrap is generated.
- Increasing costs of petroleum, the feedstock for plastics, will encourage more elaborate schemes to maximize the recovery and recycling of polymers.

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SECTION 5

STATE-OF-THE-ART GLASS WASTE RECOVERY

The recovery of glass from municipal waste within the United States today is more representative of an emerging technology, rather than an age-old practice. Nonetheless, a secondary materials industry does exist, and methods for recovering materials from municipal waste are achieving new levels of sophistication and success.

Within the recycling "closed system", three defined segments exist: (1) Glass manufacturing and secondary materials users; (2) cullet dealers; and, (3) municipal and private collection programs. Glass manufacturers are the principal actors. Raw material users have traditionally utilized glass cullet derived from off-spec glass, etc. Most recycled glass from post consumer sources has been used by glass container manufacturers to produce new containers. Recently there has been a shift to composites of glass, plastic and fibers. These new secondary uses promise glass recycling an expanded cullet capacity with reduced specification levels. Additionally, economic problems exacerbated by inflation and energy shortages have "improved" the economics of smaller scale enterprises. It has been theorized that small scale, local industries will be more apt to utilize locally-derived cullet, thereby eliminating high transfer costs (1).

Cullet dealers represent a second segment. As intermediate processors, they provide the important function of aggregation and quality control. Cullet dealers are, however, a diminishing segment of the industry. Less than 20 dealers exist today (conversation with glass cullet dealer).

Finally, the delivery or collection system, represented by grass roots recyclers, municipalities, and small businesses form the third segment. They often deal through intermediate processors, although larger programs may sell directly to a manufacturer.

Figure 8 presents an idealized drawing summarizing the major components of the industry, with sources of generation and recycled material flow (40).

In this state of the art assessment, the sources and quantities of glass wastes will be identified and quantified. Each aspect of the total recovery system will be examined using example programs or selected processes. Aspects will include procedures, labor, equipment, and other specifics. Also, technical feasibility, problems and trends will be presented. In particular, the systems for recovering post consumer glass waste from municipal sources are detailed.

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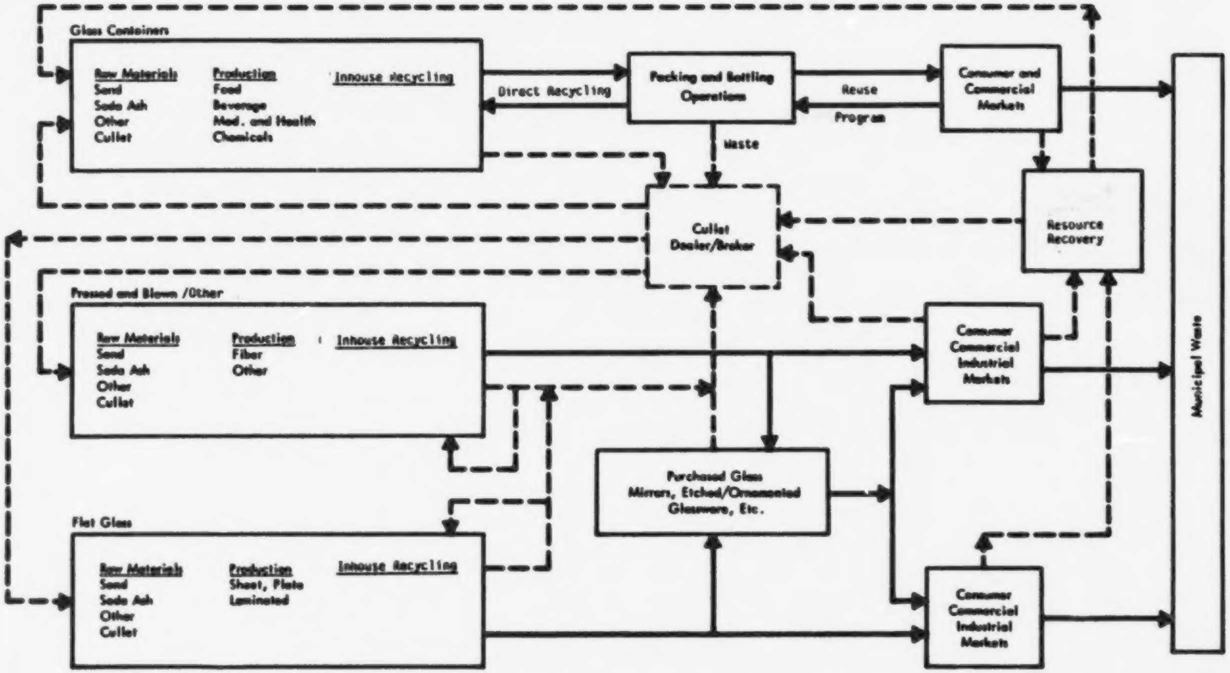

Figure 8. Glass industry recycle flowchart and sources of solid waste.

SOURCE IDENTIFICATION

Waste glass generation in the United States stems from three primary sources: industrial, commercial, and municipal. Industrial waste glass for this analysis is assumed to be any glass waste generated during the manufacturing of glassware.

Commercial waste glass is assumed to be any glass waste generated from sources where glass is used as an integral part of the establishment's product line. For example, waste commercial glass can emanate from bottle filling operations, the food packaging industry, the construction industry, food and beverage service industry (including bars), the automotive industry, and about any establishment that uses glass for their products. It is noted that commercial glass waste finds its way into the municipal waste stream or directly into landfills.

Municipal glass waste is assumed to be that glass which is discarded after the useful life of the product has ended. Examples include beverage containers, food containers and windows, etc. Industrial and commercial waste may be included in municipal solid waste and can be disposed at landfills. Retail outlets and bars may contribute to these wastestreams.

QUANTITIES OF GLASS WASTE

The total glass production in 1978 was estimated to be about 18 Gg (20 million ton). About 70 percent of this glass was container glass. However, the amount of container glass found in municipal waste is reported to be about 90 percent (41). This is expected since the useful life for container glass is relatively short when compared with other glass types such as flat glass and fiberglass, in the absence of reuse systems.

According to the latest available statistics, the amount of municipal solid waste (MSW) generated in 1977 was estimated to be 134 Gg (148×10^6 ton), which was comprised of post-consumer residential and commercial residuals (42). Glass is reported to comprise up to 10 percent of the total municipal wasteload (43).

Quantifying the exact amount of glass waste contributed by all industrial and commercial sectors of the industry is difficult. To identify and and collect data on glass waste from every industrial producer or commercial user of glass would be an enormous effort. At any rate, it is beyond the scope of this study. It will be assumed for this study, though, that these two sources of glass waste are insignificant when compared with post-consumer glass waste due to high degrees of reclamation. Table 11 presents waste glass generation estimates based on available data and inference.

Estimates of future quantities of glass waste in the municipal waste stream are numerous. Future projections of any sort are based on previous trends and many factors such as marketing conditions and competition. Table 12 presents a projection of glass waste and the amounts recovered from mixed municipal waste for the period 1980 to 1990, incorporating such factors, and beginning with the base year of 1972 (18).

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TABLE 11. ESTIMATED WASTE GLASS GENERATION BY SOURCE (1977)

Category	Total Waste	Residential			Commercial			Industrial		
		%	MT	Gg	%	MT	Gg	%	MT	Gg
--	148,000	--	--	--	--	--	--	--	--	
Glass waste	14,800	82	12,136	10,983	16	2368	2143	2	296	267
Glass container waste[a]	13,220	82	10,840	9,810	16	2115	1914	2	264	239
Noncontainer glass waste	1,580	82	1,295	1,172	16	252	228	2	31	28

[a] 90 percent of glass waste

TABLE 12. SUMMARY OF GLASS WASTE ESTIMATES, PROCESSING AND RECOVERY FOR MUNICIPAL WASTE, 1972-1985 (1,000 ton)[b]

Category	1972	1975	1980	1985	1990
Total solid waste	130,000	140,000	160,000	180,000	--
Glass available	13,200	14,500	16,400	16,600	16,900
Percent glass of total waste	10.1	10.5	10.3	9.3	--
Glass processed for recovery[a]	0	20	170	540	860
Glass recovery					
- source separation collection	175	180	225	225	225
- cullet dealers	100	85	50	50	50
- waste recovery plants	0	10	100	350	600
Total resource recovery-glass	275	275	375	600	850
Percent recovery of total-glass	2.8	1.8	2.3	3.6	5.0

[a] Processed in central facility with glass subsystem
[b] Estimates by Midwest Research Institute

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Review of Table 12 indicates that the total quantity of glass waste generated will increase slowly through 1980 while the percentage of glass in the total waste load will decrease. This is based on the assumption that glass waste recovery through 1990 will increase due to advances in recovery technology and wider community recycling efforts. This estimate could change if reuse programs and container deposit legislation efforts are successfully implemented on a wide scale.

The composition of municipal solid waste does have a direct impact on recycling programs. Although literature and source separation enthusiasts may claim that source separation is insensitive to composition and quantity fluctuations, this may not necessarily be the case. It is documented that in New England, a central processing center and source separation system was developed and keyed to aluminum and newsprint. The program was failing until a new owner recognized that glass was the key material from a collection, processing and marketing perspective. With equipment now attuned to glass processing, the program became highly successful (44). Other literature derived from "bottle bill" analyses, notes that glass is much more popular on the east coast then on the west coast, where aluminum predominates (45). A program must be designed based on site specific waste composition.

INDUSTRIAL GLASS WASTE RECOVERY

The glass manufacturing industry has traditionally recycled its in-house waste materials (factory cullet) for various economic advantages. Cullet added to the glass furnace assists the melting process of the virgin batch by lowering its melting temperature, and speeding up its melting time in proportion to the percentage added (16). As a result of heat reduction in the furnace, the life of the refractory furnace linings is extended and fuel consumption is reduced (16). Some manufacturers have also met air quality regulations by increasing cullet usage. Users report a significant reduction of particulates and high temperature related emissions (16).

In-house cullet is usually available from off-specification glassware and rejected or broken glass from within the plant. Generally, 20 percent of the batch material will end up as "in-house" cullet (16). Some additional cullet may be purchased from external sources such as bottling plants, cullet dealers, and municipal recovery programs to increase the quantity of quality cullet input to the furnace where quality control is stringently exercised (46). The maximum percent of cullet that can be introduced to a batch without altering the quality of the finished product is greatly dependent on the quality of the input cullet and how it compares to the batch recipe. Several furnaces in Europe and elsewhere are currently using more than 50 percent cullet in each batch, and some furnaces have been operated successfully on 100 percent cullet for short periods under special circumstances (47).

Currently, container glass manufacturers use more cullet than other glass sectors. Reasons for this include: (1) the glass container manufacture represents the largest industrial segment; and (2) due to short life-span, there is consistently a larger cullet supply.

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The quantity of cullet available to the glass container industry along with sources is summarized in Table 13 (48).

TABLE 13. SOURCE AND QUANTITY OF CULLET FOR THE CONTAINER GLASS INDUSTRY (1978)

Source	Total tons	Percent of total cullet
Industrial	22,757	6.7
Commercial	180,081	53.1
Municipal	136,161	40.2
Total	338,993	100.

This total amount of tonnage represents 80 percent of the cullet reported to the Glass Packaging Institute (GPI). GPI represents approximately 90 percent of the glass packaging industry, which accounts for two-thirds of the glass produced annually in the United States. It is noted here and discussed under commercial recovery that commercial sources provide a majority of the glass cullet supplied to users. This is due to high generation and aggregation factors.

Other glass manufacturers use in-house cullet as an integral part of their batch material; however, their utilization of purchased (foreign) cullet appears limited. A major influencing factor appears to be that these manufacturers are concerned over the potential contaminants in purchased cullet and its deleterious effect on their product line.

The flat glass industry utilizes nearly all in-house cullet. During the manufacturing process, broken or off-specification glass is crushed, stored and subsequently reused in their batch material. About the only glass material that would be discarded would be broken glass that has been further processed or developed into a composite that would pose potential contamination if recycled. For example, some manufacturers apply special frosting or coatings to their ware prior to shipment and any breakage would probably be discarded.

Use of foreign cullet in the flat glass industry appears small, although as a percentage of cullet used it is nearly 11 percent (49). Specifications for flat glass materials are very stringent and impurities are not tolerated. Although the container (soda/lime) glass composition is essentially the same as flat glass, such cullet is not readily used (47).

The pressed and blown segments of the industry rarely purchase foreign cullet for reasons similar to those discussed for the flat glass industry. The pressed and blown glass industry has a wide diversity of products with attendant variations in batch recipes. Manufacturer-specific glass batch formulas include such elements as lead, borosilicate, opal, etc. To mix cullet with these various glass types requires that the composition of any cullet being used be known. This has worked against cullet reuse especially

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in view of the often unknown chemical composition of the foreign cullet due to mixing from several cullet sources.

The final segment of the glass industry is the wool fiberglass segment. Manufacturers cannot reuse fibers once they are spun; however, specifications are generally less stringent and foreign cullet can be utilized. Exact amounts of cullet used have not been quantified, but the potential exists for usages up to 50 percent (50). There have been some late developments in this area. For example, a firm is currently assessing the marketability of wool glass spun from bottom ash in coal fired boilers (50).

Currently the industry is undergoing both structural and rapid change. Glass industry journals frequently note business undertakings. From these "notes", it is apparent that the industry is diversifying into new areas such as plastic-glass composites. There is a move to expand into diversified container manufacturer (glass, metal and plastics) and there are new small scale industrial operations that cost 1/3 as much as large scale operations yet produce cost effective and competitive glassware (51).

Commercial glass waste is generated from the many commercial establishments that utilize glass as an integral part of their operations or product. For example, commercial glass waste can be generated by containers broken during bottling operations or rejects from returnable bottle washing operations. This glass waste is generally returned to the glass plant in drums or bins by the same truck that delivered the bottles. Some of the glass waste can be sold to cullet dealers who process it for sale to glass manufacturers on the basis of manufacturer specifications.

There are some commercial users of glass that have glass manufacturing companies as subsidiaries of a larger corporation. In these cases, efforts to recover broken glass are simplified. One such example would be General Electric Company. General Electric has several glass manufacturing plants which supply glass components such as television picture tubes and bulbs to their finished product manufacturing plants. It is a simple matter to maintain quality control and insure backhauling of cullet (52).

It is common within the industry for primary glass manufacturers to have agreements with the commercial sources to purchase broken ware as cullet. These activities decrease the overall contribution of glass waste by the commercial sources.

Bars, restaurants and other food service related firms are generally high generators of glass cullet. Bars usually must replace their liquor bottles in original packing cartons for inventory purposes. This glass source may or may not be recycled depending on whether an agent collects the glass either through purchase or donation.

MUNICIPAL GLASS WASTE RECOVERY

Municipal waste in general is considered to be that discarded post-consumer material which is collected and disposed in the municipal solid waste system. In addition, industrial and commercial establishments discard

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wastes along with consumer waste, so that municipal solid waste can be a combination of all three types.

Glass waste in the municipal solid waste stream, as previously noted, represents about 10 percent of the total waste load. In addition, about 90 percent of the glass waste originated from container glass. As such, the container industry has been interested in recovery of this material both from an economic and public relations perspective.

The glass recovery system actually incorporates three basic operations: (1) collection or delivery; (2) processing; and (3) recycling. All three, which together comprise the closed recycling system, are interrelated and interdependent upon each other.

Glass can be recovered from municipal waste by source separation systems mechanical recovery systems or by various reuse strategies. Source separation is the simplest and oldest method of glass waste recovery, and requires separation of discarded glass from other solid waste. Source separation is generally categorized as a labor-intensive endeavor.

Mechanical separation involves the application of mineral extraction separation techniques to municipal solid waste extract glass from mixed refuse. Mechanical systems for glass recovery are at present emerging or experimental, and are usually found as a subsystem and not in an independent mode.

Reuse programs generally involve a tax or deposit on waste containers, which is redeemable upon return. The vast majority of reuse programs disappeared as the market economy favored one-way containers. However, energy and environmental considerations have spurred renewed interest in reuse strategies.

The mechanism of recycling is very similar to virgin material systems. Concentration, purification, and manipulation of material characteristics occur. Once materials are collected, they usually must be aggregated, processed, and otherwise brought up to specification levels acceptable to secondary materials users. Cullet dealers generally represent this portion of the system.

The system is closed with the purchase of cullet by manufacturers, usually glass container industries. Market dynamics, as will be discussed later, appear favorable to the use of glass cullet in secondary products, where specifications are less stringent.

In the following, each aspect of glass recovery identified above is discussed.

Source Separation

Source separation is basic to the many ecologically motivated community recycling efforts throughout the nation. Source separation actually spans municipal, industrial and commercial recycling. However, it is the difficulty of mechanically extracting saleable material from mixed waste that has sparked renewed interest in source separation.

Source separation is a traditional practice that accounts for nearly all of the glass resource recovery currently conducted. Nevertheless, making source separation an integral part of official municipal procedures has been resisted widely by public works officials who regard source separation as expensive and impractical. For example, Los Angeles, California, enjoys a good salvage market, yet county statistics show that recycling through source separation has accounted for diversion of only 2 percent of the municipal refuse stream (53). This is in a city that once had a complete source separation system (noncombustible and combustible segregation) which recovered up to 30 percent of the waste for recycling (40). From statistics as these, it is widely thought that source separation is only a waste management practice to be conducted until mechanical solutions are established.

Source separation involving either curbside collection or collection centers, has grown over the last decade. While actually an old methodology, new impetus and cost effectiveness characterize current efforts. Recycling technology is increasing in sophistication, level of efficiency and workability. New equipment, procedures, and processes have been exclusively developed for separate colection and processing. There has been an effort to standardize procedures for such programs that ensure a reliable and quality product from these operations. For glass, community recycling programs have begun seriously to incorporate processing steps and procedures in order to meet stringent market specifications or to realize the potential for increased revenues through improved product recovery. In part, this success is attributable to research funded by the U.S. Environmental Protection Agency (EPA) and other public and private agencies and industry (54).

In the following, discussion will focus on collection centers, cullet dealers and separate collection programs.

Collection or "Recycling Centers--

Most people are familiar with the community recycling center. There are over 3,000 community recycling centers which have proliferated across the nation, for reasons of community involvement, small capital expense and on the strength of a good core of participants (55). Additionally, most centers accept multimaterials (all grades of paper, metals and glass) and, as a result, are better able to weather market fluctuations, an all too common occurrence. An operational flow chart of a typical community recycling center is shown in Figure 9. Maintenance and publicity are perhaps two important components of such programs, as centers generally depend on people's enthusiasm and patronage. Presently some community recycling centers are purchasing cullet from patrons, although this is limited.

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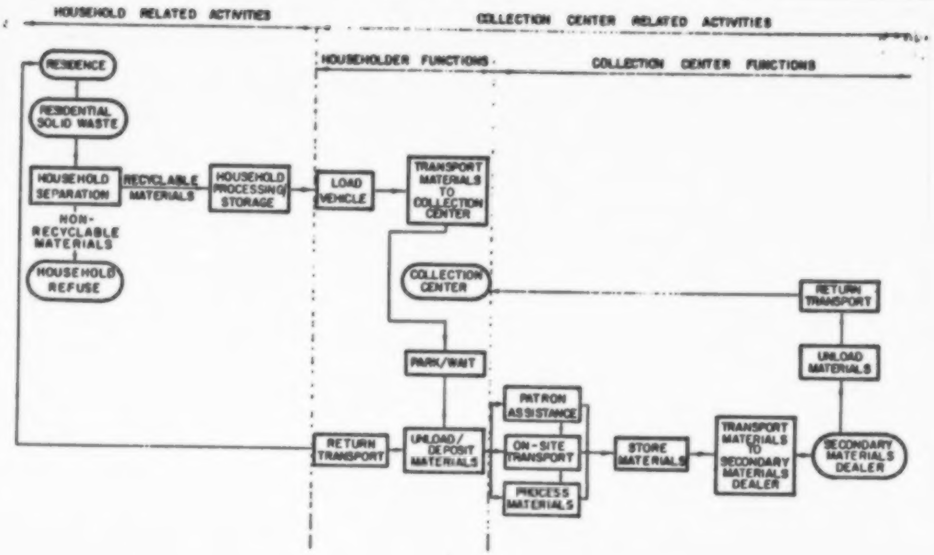

Figure 9. Systems flowchart for related collection center operations.
Source: SCS Engineers

The composition of materials brought to a center show a dependence on glass as a high volume item. Along with newspaper, glass far outweighs other materials collected at a center, as shown by Table 14 (56).

A problem with collection centers is that participation is fairly low. Use of a center by 25 percent of a community is considered good. Participation is a function of community involvement, individual incentive, and convenience of the center (55).

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TABLE 14. AVERAGE COMPOSITION OF DELIVERED MATERIALS

	Average quantity delivered (lbs/patron trip)*	
Material	Case studies#	Household study
Glass	24	19
Metal	7	7
Aluminum	1	1
Newspaper	34	53
Other+	1	0
Total	67	80

* Frequency of delivery was once per month in both instances.
# Data from five centers only.
+ Generally consisted of corrugated cardboard and/or magazines.

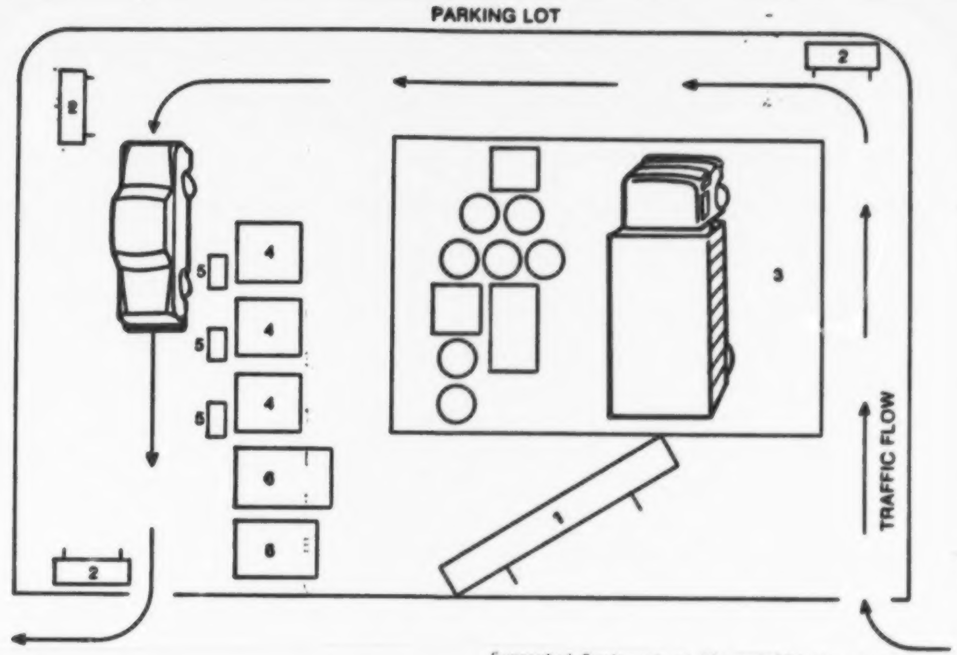
The system as described in Figure 10 begins within the homes of residents. Householders must segregate materials into designated categories depending on the procedures set forth by each reclamation project. Materials are usually washed, metal is removed from glass, and the appropriate quantities are transferred to the recycling or collection center facility.

The manufacturer "buy back" program is an interesting approach to collecting a single category of materials. GPI has proposed a scheme for such a single category collection center for glass which utilizes a payback procedure much like the current "buy back" centers for aluminum which are operated by a number of aluminum product manufacturers. Figure 10 presents a sketch of such an operation (57).

Most experts are of the opinion, though, that glass buy back would be possible only as a program element of a multimaterial collection center. Revenues that can be paid to a consumer returning glass per unit weight are insignificant when compared to aluminum recycling, for example. Almost all buyers of glass buy in quantities of known composition and quality from high volume generators or large collection operations. The center as described by GPI has not yet proven to be economical.

There is a variety of equipment germane to recycling centers for glass cullet storage and processing:

- glass conveyors
- storage barrels/bins
- glass cullet crushers
- magnetic separators
- fork lifts



1. Large sign to indicate glass collection site
2. Directional signs
3. Large container delivery and pick-up location
4. Large containers for bottle and jar deposit
5. Signs to indicate color glass to be deposited
6. Litter and trash receptacles

Suggested Equipment at Glass Collection Site

Signs
Gloves
Safety Glasses
Pliers (to remove aluminum neckbands on some bottles)
Rigid containers for glass (at least one for each color)
Containers for litter and trash
Hand truck or other equipment
(to move containers filled with glass or trash)
Clean-up brooms
Transportation Equipment
Chairs

Figure 10. Sketch of buyback operation.

Rarely are the magnetic separators and glass cullet crushers found in community operations.

For recycling centers, storage is the primary function. The main forms of storage are barrels, small bins or the common 30 cu yd roll off bin. Some roll offs may be compartmentalized. These storage containers are shown as Figures 11 and 12. When storage containers are full, they are either transferred directly to market by the center or else collected by the market.

Intermediate Glass Processors--

Intermediate glass processors or cullet dealers represent a key link in the effort to recover glass through separation. Industrial, commercial and municipal programs are increasingly dependent on the services that intermediate processors provide. As secondary materials dealers, they do not produce new glass, but instead act as the purchase agents for a number of glass manufacturers. There are fewer than 20 cullet dealers in the United States. They are located in New England, Florida, California, Missouri, Houston, and the Great Lakes region (40).

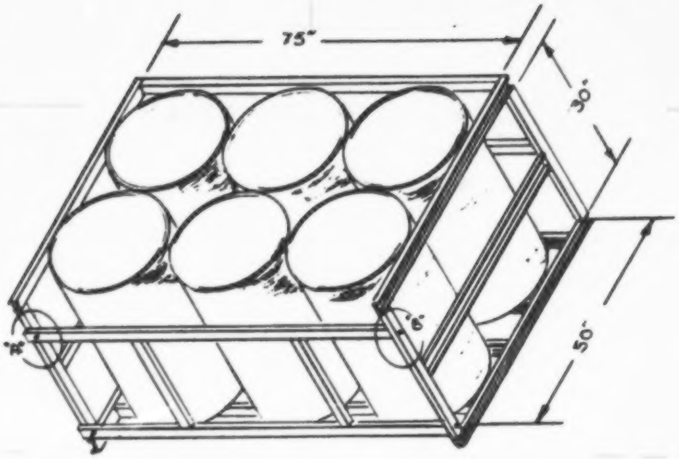


Figure 11. Barrel storage by Recycling Enterprise, Inc. (REI)

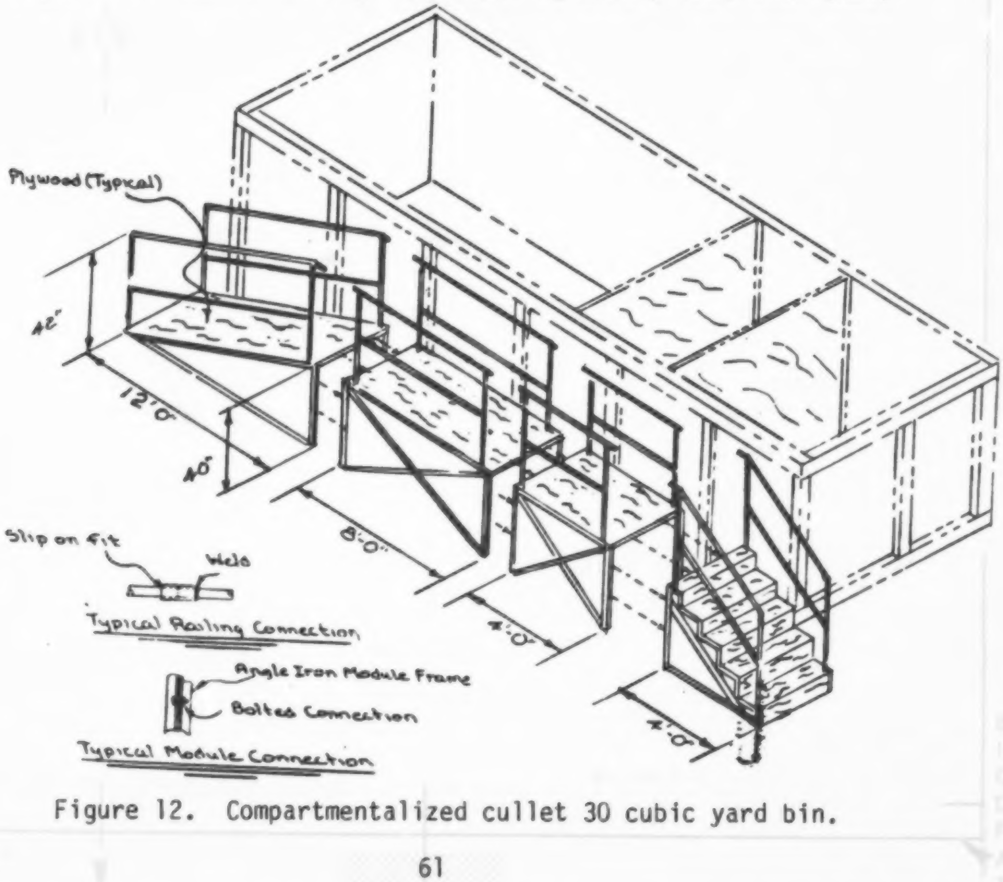


Figure 12. Compartmentalized cullet 30 cubic yard bin.

By providing storage equipment to large manufacturers, cullet dealers collect scrap glass which might be disposed due to contamination. They remove contamination through their processing system, and then sell it back to glass manufacturers. By providing storage equipment to local recycling groups, they provide a service in collecting heretofore unreclaimed glass. Cullet dealers also are able to collect glass from restaurants and bars. Containers may be provided along with employee education programs.

Some intermediate processors may serve as mixed recyclable purchasers for recycling groups. In Los Angeles, California, one cullet dealer is the sole purchaser of recyclable material, including cullet, from the Downey DART source separation program. In that operation, collection vehicles transfer glass cullet and other material collected directly to the glass processor. The cullet dealer separates metals and paper from the scrap glass, and sells all components.

The intermediate processor collects materials which are then transferred to a central depot or processing yard. Material is brought in and normally stored in bunkers prior to processing, as shown in Figure 13. Glass is then periodically fed into a variable feed hopper, magnetically separated from ferrous material, crushed, then aluminum and plastics are picked out by hand or screened. The remaining material is conveyed to appropriate loading and/or storage areas. Glass may also be washed to remove organics. This operation is shown in schematic in Figure 14.

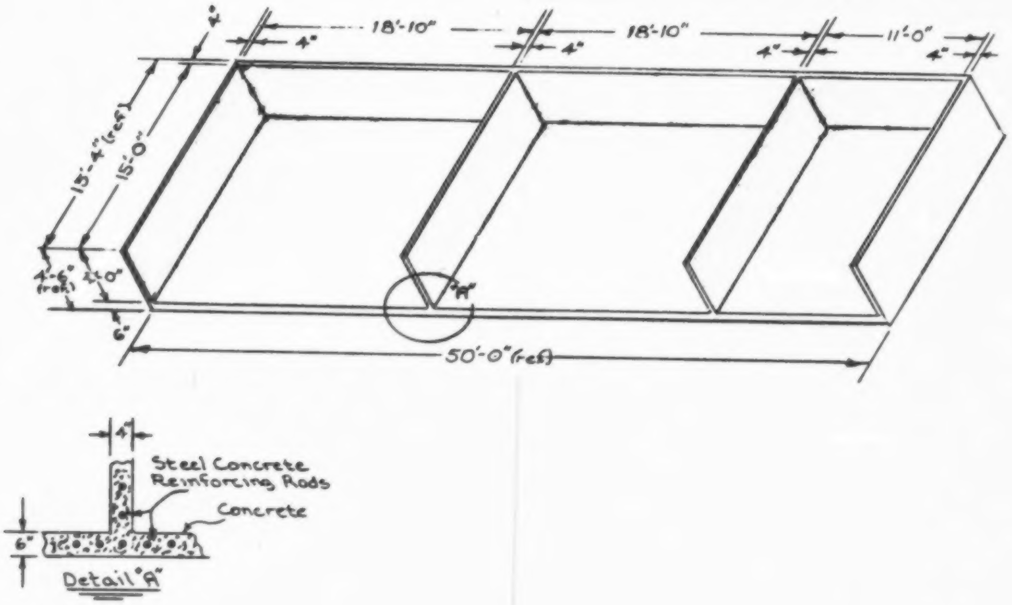


Figure 13. Bunkers for cullet storage (REI)

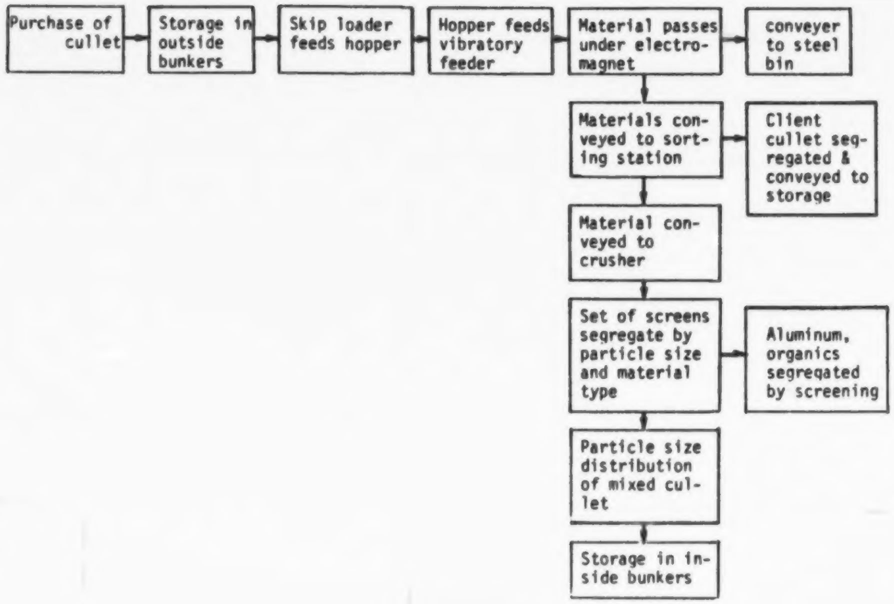

Purchase of cullet
Storage in outside bunkers
Skip loader feeds hopper
Hopper feeds vibratory feeder
Material passes under electro-magnet
conveyer to steel bin
Materials conveyed to sorting station
Client cullet segregated & conveyed to storage
Material conveyed to crusher
Set of screens segregate by particle size and material type
Aluminum, organics segregated by screening
Particle size distribution of mixed cullet
Storage in inside bunkers

Figure 14. Immediate processing schematic (Circo Glass, Inc.)

New developments for intermediate processors concern the availability of funds which allow improvements to operations with better service to clients. In California, for example, two cullet processors received several thousand dollars to plan effective publicity, purchase equipment, and improve procedures as a result of the state's SB650 program ("litter tax"). In New England, the EPA, the Small Business Administration, and the National Science Foundation have assisted cullet dealers in investigating new technology, confirming economic feasibility, and in expanding markets (58).

Separate and Integrated Curbside Collection Programs--

Most of the recent research and successful glass recovery has come from multicategory source separation schemes involving curbside collection. Curbside collection programs generally operate in residential areas. There are approximately 220 such efforts on-line in the nation (59). In a typical program, residents routinely set out for collection using barrels, bag, and boxes, recyclable fraction(s) segregated from refuse. Either separate trucks or integrated collection vehicles collect the recyclables and/or refuse. Material is normally taken to a processing station where, if glass materials are already segregated in glass colors or type, minimal processing is conducted. Where recyclables are mixed, hand or mechanical sorting is required. Long term storage may or may not occur depending on volume. Table 15 lists the types of equipment to be considered for source separation programs. Figure 15 presents a schematic of operations at a central processing station.

TABLE 15. TYPES OF EQUIPMENT TO BE CONSIDERED FOR SOURCE SEPARATION EQUIPMENT DATA BASE

Collection	Storage	Processing
a. Simultaneous collection Refuse truck and trailer Refuse truck with racks Refuse truck with compartments Other	a. Loading docks b. Buildings Brick Steel Prefab	a. Separation Blowers Screens Magnetic Conveyor/hand operations Other
b. Separate collection Compartmentalized trailer Compartmentalized trucks Panel trucks/vans Stake bed trucks Box bed trucks Container trains Other	c. Storage equipment Roll-off containers Bins Self-dumping containers Other	b. Can flatteners c. Glass crushers d. Balers
	d. Conveyance Forklift Hoist Conveyor Other	e. Conveyance Forklifts Conveyor (belts, rollers) Pallet jacks
	e. Other	f. Other

Source: SCS Engineers

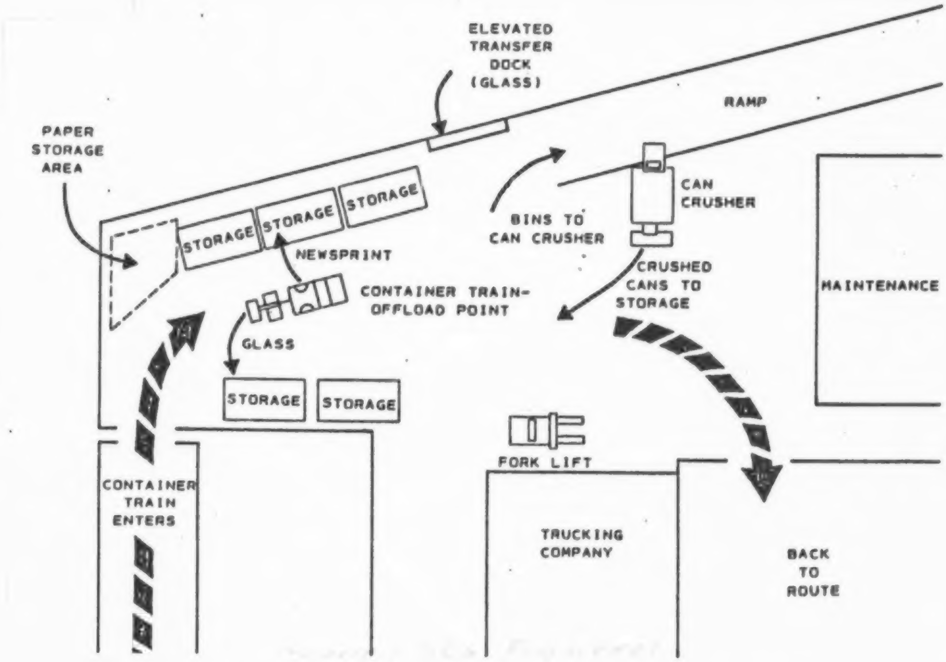


Figure 15. Central materials processing station
Source: SCS Engineers

In the typical multicategory program, less profitable items are usually supported by more profitable items. Aluminum metal, newsprint and high grades of paper are representative of high margin items, while glass and other metals (such as ferrous) are low revenue, high weight items. Collecting all these items in tandem, though, allows a program to meet an economic break-even point. There are no curbside collection programs solely collecting glass in the United States. Approximately 35 programs collect glass along with other materials (59).

The critical elements for separate collection are labor and collection equipment. Examples of collection vehicles are shown in Figure 16. Explanation of integrated vs separate collection follows.

Integrated collection--In integrated collection, the current refuse collection system accomodates the collection of materials. Most often, this is through the use of compartmentalized vehicles or use of racks, trailers or bags. The racks and bags are placed at appropriate spots on the refuse collection vehicle. To date, few integrated collection programs exist which recover glass waste. Most likely, racks and bags are used for aluminum or newsprint. Figure 17 presents a generalized schematic of an integrated collection system. An example of an integrated collection program which collects glass is in New London, Connecticut. Open trailers are attached to the rear of the regular collection trucks and mixed recyclables are collected. 125 tons per month of recyclables are recovered.

There are advantages to integrated collection systems such as lower capital costs, the ability to collect on route, and no additional collection labor. Significant disadvantages remain, however. The trailer reduces maneuverability, is illegal in some states, and the crew must periodically leave a route to offload the trailer.

Separate collection--In separate truck collection, dual systems exist for collection of recyclables and refuse. There are a variety of designs, most utilizing converted stake bed vehicles or pickup trucks. One firm in California has designed a new system for separate collection using a "container train" approach (61). This system is used in Fresno, California. Predecessors of the container train were implemented in San Luis Obispo and Modesto, California.

An idealized schematic of separate truck systems for recovery is shown in Figure 18. It is noted that while integrated systems do not normally recover glass, separate collection vehicles are more likely to incorporate such a recyclable component.

Advantages of separate trucks include: elimination of capacity limitations, crew inefficiencies and an ability to collect all types of material. Disadvantages include: high costs of labor and energy, and scheduling confusion.

Perhaps the most familiar of separate truck collection programs is the EPA-sponsored separate collection program in Marblehead, MA. In that effort, a specially adapted rear loader packer (with compaction equipment

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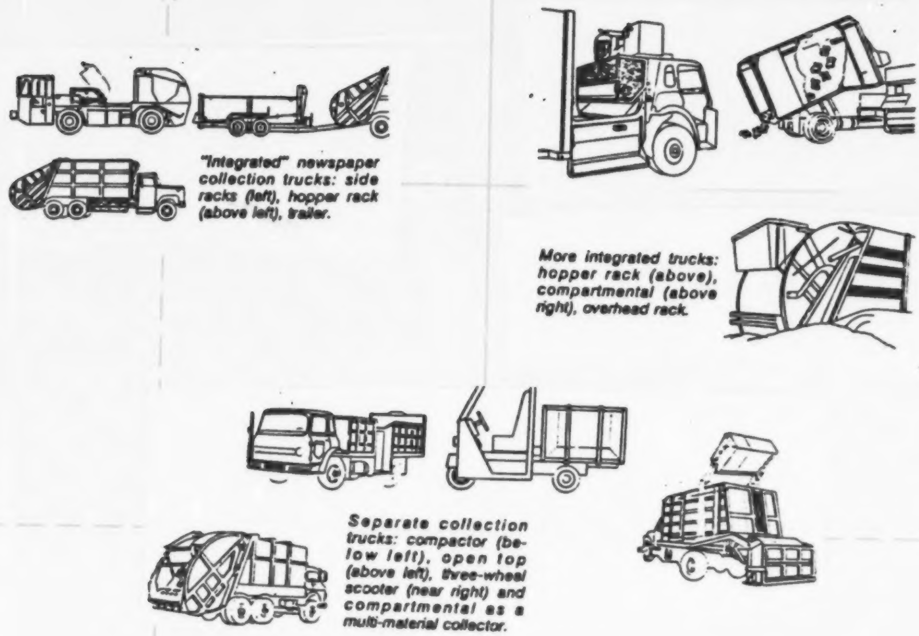

"Integrated" newspaper collection trucks: side racks (left), hopper rack (above left), trailer.

More integrated trucks: hopper rack (above), compartmental (above right), overhead rack.

Separate collection trucks: compactor (below left), open top (above left), three-wheel scooter (near right) and compartmental as a multi-material collector.

Figure 16. Overview of curbside collection vehicles

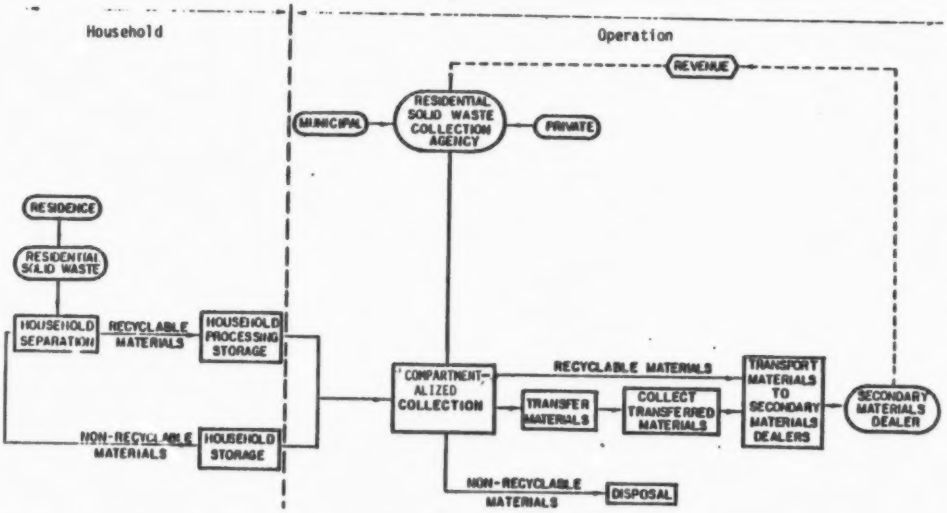

Figure 17. Flowchart of integrated collection.

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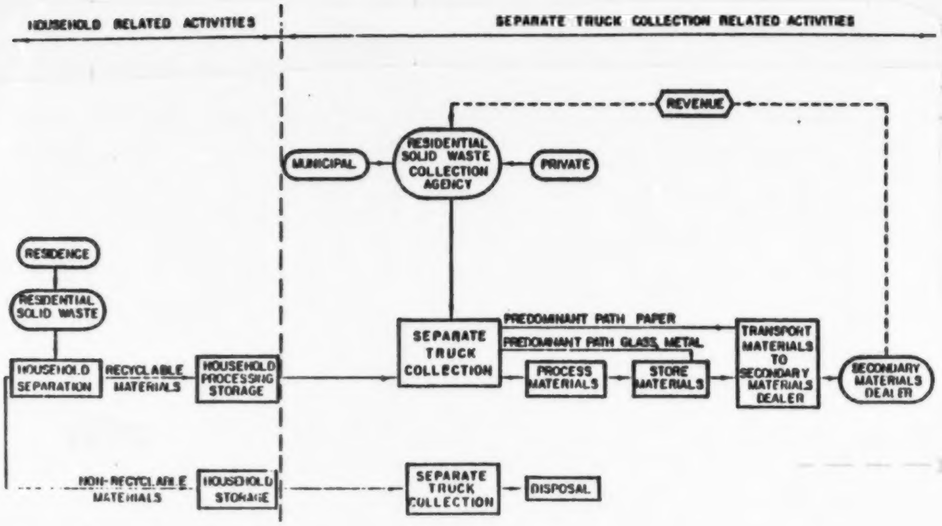
HOUSEHOLD RELATED ACTIVITIES
SEPARATE TRUCK COLLECTION RELATED ACTIVITIES
REVENUE
MUNICIPAL
RESIDENTIAL SOLID WASTE COLLECTION AGENCY
PRIVATE
RESIDENCE
RESIDENTIAL SOLID WASTE
HOUSEHOLD SEPARATION
RECYCLABLE MATERIALS
HOUSEHOLD PROCESSING STORAGE
SEPARATE TRUCK COLLECTION
PREDOMINANT PATH PAPER
PREDOMINANT PATH GLASS, METAL
PROCESS MATERIALS
STORE MATERIALS
TRANSPORT MATERIALS TO SECONDARY MATERIALS DEALER
SECONDARY MATERIALS DEALER
NON-RECYCLABLE MATERIALS
HOUSEHOLD STORAGE
SEPARATE TRUCK COLLECTION
DISPOSAL

Figure 18. Flowchart of separate collection.

removed) would periodically collect segregated glass (by color), paper and metal cans from residents.

The EPA also sponsored, in San Luis Obispo, California, a separate collection program involving collection by a private hauler using a container train and two additional employees. A central processing facility is located at his maintenance yard. Processing equipment and market transport are provided by the market brokers. This program was unique in that the nearest markets were at least 200 miles distant.

In Downey, California, the DART Program collects mixed recyclables (i.e., paper, glass and metals) in one container and then, at a processing yard belonging to a scrap glass broker, the material is sorted using a combination of handpicking from conveyor lines and magnetics.

These programs described above represent state-of-the-art.

Innovative design--One innovative design in source separate curbside collection has been recently introduced (62). A compartmentalized vehicle allows simultaneous collection of refuse and at least three categories of recyclables. It is compatible with most refuse collection systems. The impetus behind the design is to reduce scheduling confusion, capacity problems, energy usage, and inconvenience.

The system offers:

- total (4 waste category) capacity of 20 cu yds
- conventional loading and unloading features
- competitive capital cost to conventional packers where recycling credit is allowed.
- no additional labor requirements

The system combines a 15 cu yd packer mechanism with 5 cu yd capacity for recyclables, which is reasonable for current on-line programs (62). The recycling module is placed between the packer body and the cab, and is side loaded. Glass, metal and newsprint have 111 cu ft, 111 cu ft, and 56.5 cu ft capacity, respectively, for on-route storage.

A performance test was conducted for 3 months on the vehicles, and it appears that about 6 seconds are added to each recycling household over normal refuse collection. Designers anticipate that the vehicle will add medium incremental costs to collection operations (62). It has not been extensively tested for durability or fluctuations in waste stream composition.

Another innovative design relates to collection categories. Normally, waste is segregated into three recyclable fractions and refuse. However, the Downey Dart program was noted as collecting mixed recyclables (e.g., glass, paper and metal together in one container). This design has been adopted by Atlantic County, New Jersey, recently. The mixed recyclables in Atlantic County will be collected by existing packer trucks on a twice a month basis, in lieu of normal refuse collection. It is noted that Atlantic County has twice a week refuse collection so the scheme does not interfere with health regulations. The system, while curtailing capital costs in collection and simplifying scheduling and collection procedures, incurs considerable processing cost in manual and mechanical separation of the collected fraction. Projected economics tentatively show the operation capable of achieving break-even point (63).

Mandatory vs voluntary programs--A consideration for source separation programs revolves around the question of mandatory versus voluntary compliance. To date, most programs have been voluntary (either city-wide or subscription). In these programs, participation has been generally low, ranging from 2 - 30 percent. This has led some experts to doubt the viability of curbside collection and the ability to increase participation to an effective level. There are, however, reasons to believe that many people who do not participate in voluntary programs, may actively support mandatory programs. In New England, several systems have incorporated mandatory compliance and results have been encouraging. One 1978 study involving a fully integrated incineration-source separation system in Nottingham, New Hampshire, tested compliance versus noncompliance of a mandatory system. Further, it tested compliance related to municipal and individual contracting for service, and personal delivery of refuse to landfills as is practiced in many rural communities. Compliance averaged above the 90 percent level consistently for one year. Of particular note is that glass recovery was consistently highest in terms of meeting projected collection levels based on estimated waste quantities. It was inferred that mandatory compliance coupled with good public relations was a key to successful source separation (64).

Another study conducted by the Naval Construction Engineering Research Laboratory in 1976 found that a mandatory source separation collection of recyclables at Fort Bragg, NC achieved 90 percent participation of residents. This 3 month test did not achieve economic brakeven status. Glass, paper and cans were collected (65).

Source Separation Programs--

Table 16 presents all source separation programs, and their design variables, that collect glass as one component of a recyclables stream.

Mechanical Separation

High technology recovery systems are emerging for glass recovery. While these systems do recover other materials as well, only the subsystems applicable for glass recovery are addressed in detail. While no subsystem has as yet been proven on more than an experimental basis, extensive research continues to attempt achievement of viable and cost-effective mechanical separation.

Froth Flotation for Glass Recovery--

Froth flotation is an emerging technique for glass waste recovery. This technique has been extensively tested by the Bureau of Mines, and by the NCRR at its full-scale operation in New Orleans called Recovery I. The test results indicate low refractory particle content cullet is recovered (66). It does not, however, meet industry specifications for glass container manufacture (66). Froth flotation is a technique utilizing differences in the chemical properties of fine ground glass and the contaminants to achieve material separation. The glass and contaminants are mixed with a physiochemical reagent, which is absorbed preferentially on the surface of the glass. The coated glass attaches to bubbles formed by agitating the mixture with air.

This glass-rich froth rises, is swept off the top, and is washed. Commercial glass-sand operations and other reprocessing operations have been using the froth flotation principle for decades to separate silica sand or other ores from unwanted minerals. Normally a series of froth flotation cells are used where progressively more and more of the contaminants in the glass are removed.

The Recovery I process in New Orleans is considered the most advanced state of the art in mechanical recovery. Therefore, the system is selected for further investigation. In the Recovery Process, the residue (material or "tailings" not floated off) is pumped to the process water cleanup system. Here, suspended solids are settled out and discharged to landfill. Some of the water is recycled in-plant, while the remainder goes to a lagoon for reduction of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) by oxidation.

TABLE 16. SOURCE SEPARATION PROGRAMS COLLECTING GLASS WITH DESIGN VARIABLES

Site	Collection method[a]				Material contract	Mand. ord.	Scavenging ord.
	R	T	CV	ST			
East Lyme, CT				x		x	
Newington, CT					x		
Waterbury, CT				x	x		
Waltham, MA				x	x		
Andover, MA				x			x
Bedford, MA				x			
Newton, MA			x				x
Somerville, MA			x		x		x
Marblehead, MA			x			x	
Hamilton, MA				x			
Tiverton, RI[b]				x			
Summit, NJ				x	x		x
West Orange, NJ				x		x	x
Bound Brook, NJ				x	x		x
Ithaca, NY				x	x		
Bowil, MD				x			x
Albington, PA				x		x	x
Clifton Heights, PA				x			
Atlanta,		x					
Walbash, IN		x					
Boulder, CO				x			
Downey, CA				x		x	
Fresno-Clovis, CA				x		x	
Davis, CA				x		x	x
San Luis Obispo, CA				x	x		
Modesto, CA				x	x		
El Cerrito, CA				x	x		
Santa Rosa, CA				x	x		

[a] R = Rack, T = Trailer, both are integrated collection; CV = Compartmentalized vehicle, ST = Separator Truck

[b] This program is the only one to solely collect glass via curbside collection. Programs generally collect newsprint and metals in varying combinations.

Note: This listing is not inclusive.

The recovered glass is dewatered by a vacuum filter to a moisture content of less than 10 percent. This device has a rotating table, covered by a very fine filter on which moist glass is deposited. The space under the table is evacuated by a vacuum pump which draws the moisture from the glass. After one revolution, the glass passes under a scroll discharge and is removed from the table. Processed glass is then dried and stored (67). Figure 19 presents a schematic of this process.

Optical Sorting for Glass Recovery--

Optical sorting is designed to remove any foreign material from a glass-rich fraction of a waste stream and to separate the glass by color. This method of separation is commonly used in the food processing and other industries and has been modified for the purpose of glass recovery. It is considered a new technology for glass recovery.

Considerable research has been conducted on the propietary Sortex machine. The Sortex machine consists of a series of photocells which separate the opaque particles from the transparent particles by matching the intensity of light transmitted through the particles with a fixed shade background. In the process, glass-rich fragments are charged to a Sortex

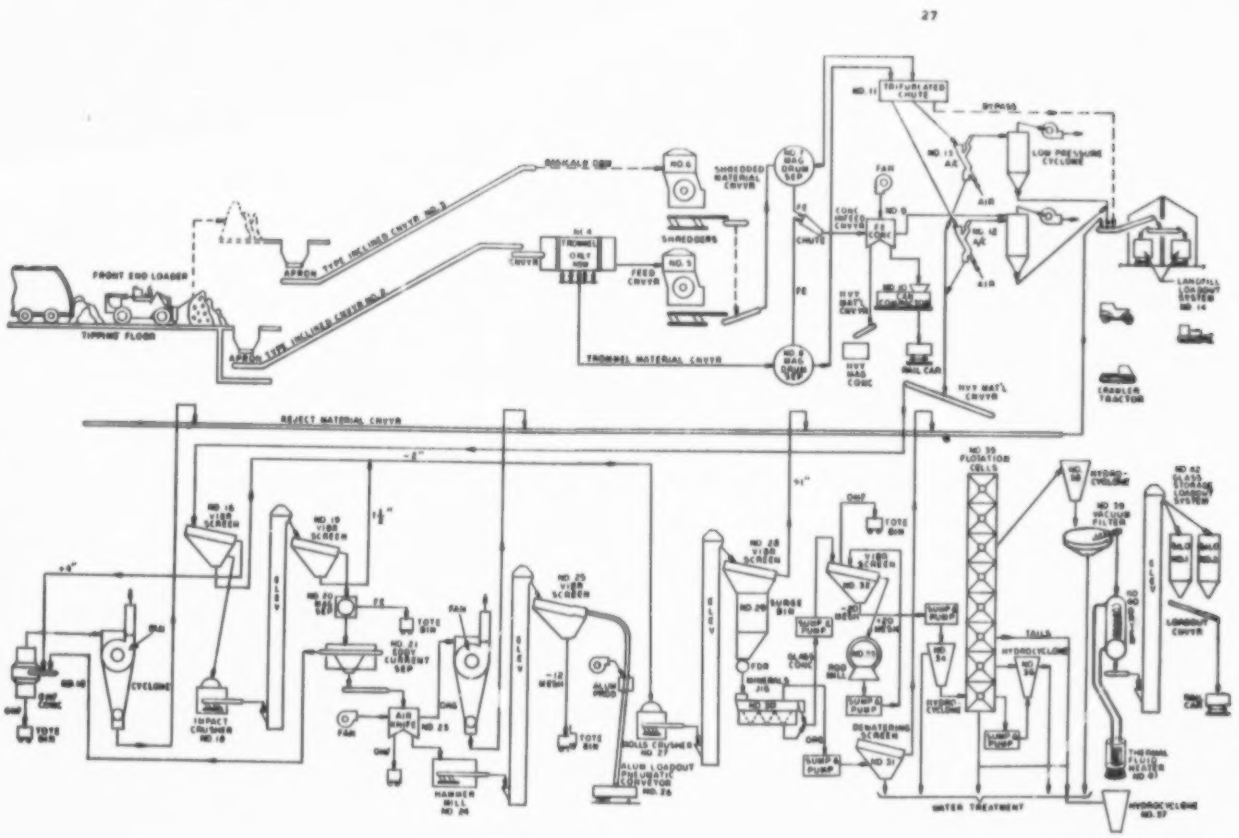

Figure 19. Recovery 1 Flow Diagram.

machine via high speed belts. When the particle does not match the corresponding background, a jet of air is automatically released, and the particle is deflected into the appropriate receiving bins. The transparent particles, comprised of primarily glass particles, are also color sorted in the photocells by the similar mechanism.

This method of separation is most effective when the particle size of the feed stream is larger than 6 mm (1/4 in) since the particles are examined individually as they pass "single file" through the sorter.

A series of tests were conducted by EPA at a resource recovery plant in Franklin, Ohio (68). Initial findings indicated that contamination levels of refractories were excessive but encouraging. Flint glass averaged six refractories per pound, and the color mixed fraction (green and brown) contained 25 refractories per pound (68).

This Sortex system was selected for a resource recovery system in Hempstead, NY based on encouraging work done at the pilot Franklin, Ohio plant. Technological improvements in the Sortex optical sorting equipment indicated a high probability of success which could be overcome with further refinements (68). While the operations have been connected with "high tech" systems, Section 8 will report on a proposal by a cullet dealer to segregate colors by this type of method.

Systems for Concentrating Glass Wastes--

Several other preprocessing methodologies can be used to produce glass-rich fractions from which glass can be separated. These are usually operated alone or in conjunction with other units to provide suitable fractions for subsequent froth flotation or optical separation systems.

Air classification is normally used as a preprocessing step for the complete solid waste recovery systems. There are two basic ways in which air can be injected into the system to achieve the separation of waste materials by weight. The first way of separation involves air flowing horizontally through a falling stream of solid waste material (69). Heavy fractions of the waste stream are unaffected by the air flow and fall to the bottom of the classifier. This bottom fraction primarily consists of a mixture of glass, aluminum and other nonferrous metals, and is occasionally mixed with some organic materials. In the second method of air classification, shredded solid waste is introduced into the side of a vertical tube with a rising air flow (69). Light particles are carried out the top of the tube by an air stream, while heavy particles settle out at the bottom and are conveyed to subsystems for additional separation.

Both air classification systems essentially segregate the light (organic) fractions from the heavy (inorganic) fractions, as found in the solid waste stream. However, a small portion of the light fraction will be contained in the bottom portion, and a certain amount of heavy particles will be carried over in the light fraction.

The rising current separator is a means for recovering nonferrous metal and glass from the heavy fraction of the waste stream (70). Prior to allowing the material to enter the separator, the incoming refuse is first air classified to remove most of the light organic fraction, magnetically separated to remove ferrous metal, and finally screened to remove the fines and oversized particles. The particle size of the separator's feed stock is between 0.6 and 5 cm (1/4 inch and 2 inches). In the separator, water is continuously pumped through the system. As a result of the rising water current, light organics remaining in the heavy fractions are carried to the top and removed. Heavy fractions at the bottom of the separator consist of mixtures of glass, rock aluminum and other nonferrous metals, which can be further processed to obtain individual species.

Heavy media separation is another technique for concentration. The system is based on different specific gravities of the incoming material. The separator is basically a tank consisting of heavy "liquid" (suspension of a mineral in water) which acts like a single fluid with high density.

As the mixture of glass, aluminum and other nonferrous metals is fed to the separator, glass and aluminum (of lower density) float while the other metals sink. The glass and aluminum are skimmed off for further processing.

Shredders, screeners, and jiggers are often used to augment the above described components for concentrating glass waste fractions.

Current High Technology Resource Recovery Programs in the United States--
Table 17 presents a partial listing of current resource recovery programs that recover glass as one product (71). These resource recovery programs do not now render a saleable glass product.

Reuse Strategies

There are other methods for recovering glass materials from the waste stream. One of these is deposit legislation. Another is the collection through buy back programs of bottles for washing and reuse.

In the former, a legal mechanism is initiated which places a deposit on containers at point of consumer purchase. This was the traditional system that was essentially supplanted by the one-way container system. In theory,

Table 17. RESOURCE RECOVERY ACTIVITIES WHICH RECOVER GLASS

Location	Process	Output	TPD Capacity	Capital $mm	Status
Baltimore County, MD	shredding, air classifying	secondary product glass	600-1000	8.4	operational
Bridgeport, CT	froth flotation	glass cullet	1800	5.3	not in operation
Dade County, FL	"hydroposal"	glass cullet	3000	165.	1981 startup
Milwaukee, WI	air classifying	glassy aggregate	1600	18.	in operation
Monroe County, NY	froth flotation	mixed glass	2000	50.4	started up Aug. 1979
New Orleans, LA	froth flotation	glass cullet	700	9.1	operational problems
Hempstead, NY	"hydraposal"/sortex	color sorted glass	2000	73.	shakedown
Wilmington, DE	froth flotation	glass cullet	1000	51.	under construction

the consumer returns the container to the retailer to reclaim the deposit. Once returned, the retailer stores the container until it is returned to the bottler. There are bottle deposit systems now in place in several states including Michigan, Vermont, Connecticut, and Oregon.

In response to deposit systems, it is noted here that industry has advocated a litter tax program. Such programs levy manufacturers, retailers, etc. a small annual tax that is collected by state agencies and later parceled out to recyclers through the form of grants or loans. This system has been implemented in California and Washington and has been seemingly successful, both in dampening enthusiasm for bottle bills and in encouraging recycling.

Another form of reuse is characterized by the ENCORE! bottle washing operation which originated in Alameda County in 1975 (72). Recognizing that the 74 million gallons of wine consumed annually in California require over 110 thousand tons of glass "throwaway" bottles, ENCORE! attempted to demonstrate to wineries, recycling centers, restaurants, stores and concerned groups and individuals that empty wine bottles could be collected, washed, and reused on a large scale.

Used wine bottles are collected and returned to a central sorting warehouse in Berkeley. There, they are washed and sterilized in an hydraulic bottle washer custom-designed for ENCORE! and incorporating special energy saving techniques. Also, ENCORE! is currently heating water by utilizing solar energy. The "revitalized" bottles are then distributed to participating wineries.

ENCORE! maintains the strictest quality control standards and meets all state, local and Federal health regulations. Identification of such areas around the United States where such programs could be implemented has not been conducted. It is also noted here that GPI has not promoted this form of reuse due to the opinion that health and safety risks associated with reusing the washed bottles outweigh the potential conservation benefits.

MARKETS AND SPECIFICATIONS

The waste glass recovery cycle is closed when materials are ultimately delivered to and utilized by a market. Markets or users of glass derived from post-consumer solid waste, though, are not as well developed as for other recyclable materials such as fibers and metals. Reasons include the extreme nature of specifications, the need to color sort glass and the ready availability of raw resources for container manufacture.

In California, mixed cullet markets are excellent primarily because of the wine bottling industry. The industry utilizes green glass, hence color specifications are not as stringent as for other commercial users. As a result, color manipulation can be conducted using amber, green and flint. Using this approach, cullet dealers are able to effectively mix various glass cullets from different sources to derive an acceptable glass cullet meeting a users specifications. Dealers and glass manufacturers are able to buy both color sorted and mixed glass cullet. Also, the marketing arrangements have been strengthened by two other factors:

1. the numerous programs and increasing sophistication of processing
2. the presence of a "litter tax" program which has favorably impacted glass recycling. Each year, over $12 million is accorded litter, recycling and resource recovery activities.

On a national basis, it appears that new secondary product applications such as fiberglass insulation will spark growth in glass recycling over the near and long term. A reason is these products require less stringent specifications on color and contamination.

Specifications

The specifications or standards are dictated by the particular product or application being considered. In the case of containers, the standards are rather well-defined and quite rigid. On the other hand, for the vast majority of other products and potential products which could utilize secondary glass, the standards are either very broad, vague, or essentially nonexistent (40). Glass manufacturers have to keep close control over the batch of raw materials to maintain the quality of the finished product. The cullet extracted from mixed municipal solid waste generally consists of foreign particles and chemical compounds used in coloring container glass. These contaminants must be removed to a level which is acceptable for use in a buyers batch recipe, or else masked effectively. A problem exists, though, as glass manufacturers either lack the space necessary for storage of cullet, or the wherewithall to upgrade cullet. Therefore, a tendency exists to refrain from buying cullet except from known proven sources.

Color

There are three basic colors of glass containers produced: clear (flint), green, and amber. About two-thirds of the glass produced is clear.

To be acceptable to the container manufacturer for use in making flint glass, the cullet must be at least 95 percent clear. Similarly, color-sorted cullet labeled "green" or "amber" can contain only limited amounts of other colors. These specifications are listed below (73):

Cullet Color	Amber (%)	Flint (%)	Green (%)
Amber	90-100	0-10	0-10
Flint	0-5	95-100	0-1
Green	0-35	0-15	50-100

Waste glass meeting these color specifications provides the industrial user with reasonable assurance that his final product will not be offcolor, and, therefore, will meet specification requirements.

Though mixed color cullet is generally thought to be acceptable for use in green or amber containers, many companies are uncertain of the amount of this material their furnaces will tolerate without causing their product to be off-spec (73). This area continues to be a research and demonstration problem.

Contaminants

Whether sorted by color or not, glass cullet will not be accepted by container manufacturers unless rigid contaminant limitations are met. Contaminants include metals, organic materials, ceramics (refractories), and excessive liquids. Refractories are by far the most serious concern at this time.

Contaminants cause the formation of "stones" in glass containers. While contaminants may be introduced by low quality cullet, refractory material detached from furnace construction and poor furnace operation may also cause "batch stones."

The general glass cullet specification for container manufacturing is listed below:

- % wt: S_iO_2 (66-75), Al_2O_3 (1-7), CaO + MgO (9-13), Na_2O (12-16)
- Cullet must be noncaking and free flowing
- Cullet must show no drainage from the sample with 0.5% wt moisture content
- Maximum 0.2% organic content (dry weight sample)
- 100% 50mm, 15 wt % 0.11 mm (140 US mesh)
- less than 0.14 % magnetic metal content; no particle to exceed 6 mm
- Nonmagnetics: all particle 6 mm 9 mm (20 US mesh), no more than 1 particle per 18 Kg
- Inorganic materials: 0.14 wt % with no particle 6 mm
- Refractories:

Mesh Size	Particle Size, Pmm	No. of Particles
+20 mesh	P 0.85	1 per 18 Kg
20 x 40 mesh	0.85 p 0.43	2 per 450 g
40 x 60 mesh	0.43 p 0.25	20 per 450 g

Exact specifications are provided in ASTM specification No. E708-79, ASTM Book Part 41, 1980 issue.

For other industrial segments, particularly secondary products such as fiberglass, general cullet specifications are relaxed or nonexistent. The following examples are given to illustrate the nature of the specifications in some of the product areas (74):

1) Brick and concrete aggregate: can use up to 50% glass cullet. Preferably without metal or organics.

2) Foamed glass: can use up to 95% glass as is (without cleaning, sorting, or sizing).

3) Ceramic tile: can use up to 40% to 60% glass which is uncleaned, unsorted, and sized to -5, +200 mesh.

4) Terrazo tile: can use about 60% glass with no metal since about 70% of the aggregate must show on the surface.

5) Building panels: can use up to 94% glass with no metal or any material which will rehydrate. Material to be sized to 200 mesh.

6) Glass Wool: can use about 10% to 50% glass cullet with up to 20% foreign material which includes organics, metals and ceramics. This is the only product using secondary cullet which is currently manufactured on a commercial scale. It is made by the Sealtite Corp., Merton, Wisconsin.

7) Slurry seal: can use up to 100% of the necessary aggregate as waste glass. Cullet should be sized from -3/8 to 200 mesh and must be of neutral pH and contain no expansive plates. Small amounts of metal and organics may be tolerated.

8) Glasphalt: can use up to 77% waste glass sized to minus 1/2 inch. Acceptable paving material has been tested containing up to 15% of nonglass components that appear in the waste stream.

The major problem with these applications is being able to compete economically with virgin resources.

Market price--

Purchase prices for materials collected and meeting specifications vary across the U.S. Selling prices have not varied considerably since ample supplies of raw material are available to compete with recycled materials. In fact, a large deposit of glass-type sand was found in California recently (9000 acres) (51).

Prices paid to consumers range from $10-30 per ton depending on color segregation, FOB (freight on board) point, demand, and contaminant level. Prices paid to cullet dealers generally range $20-50 per ton which reflects costs of processing, transporting, aggregating and profit margin. It has been reported that some cullet dealers have received as high as $100 per ton delivered FOB glass plant, but this is extremely rare.

FUTURE TRENDS IN GLASS RECOVERY FROM MUNICIPAL WASTE

Glass recovery from municipal solid waste is limited at present. The EPA estimates the current recovery rate to be 4 percent (75). There is some impetus being given to increase glass cullet usage through national energy and resource conservation efforts, and stringent air quality control regulations. Stringent specifications, the lack of a national mixed cullet market, manufacturer reluctance to maximize cullet usage in batches, and ready availability of appropriate silica sand deposits tend to reduce growth trends.

Several trends have been identified from conversations with acknowledged industry experts and current literature. These are listed below:

- increase in smaller scale operations (economy of scale)
- reduced distribution lines
- more emphasis on fiberglass production, insulation and plastic composites
- increase in mixed cullet recycling
- reuse program resurgence
- source separation has emerged as the dominant recovery strategy
- continued inroads by plastics into traditional glass packaging markets will spur glass manufacturers into secondary products.

The trend toward smaller scale production coincides with the rising cost of energy, transportation, and stiffening competition in the packaging industry. Changing economics have benefited smaller scale operations to such a degree that Graham Fiber Glass of Ontario, Canada is currently constructing a plant that has an 11,000 ton per year capacity. The $10 million facility produces glass insulation at costs comparable to plants costing 2-3 times as much (51).

Increased emphasis on secondary products and mixed cullet recycling almost "go hand in hand". Traditional reliance on glass container manufacturers for the purchase of recycled glass has tended to limit recycling of cullet because two-thirds of all glass containers are flint (clear). Mixed cullet is normally not usable in clear glass container manufacture. A boon to secondary product manufacture has been the energy crisis. To maximize conservation efforts, the Federal government specifications for insulation call for the use of a percentage of recycled material.

Deposit programs enforce a reuse consciousness. Currently, industry and environmental/consumer organizations are vying in several state legislatures for the votes necessary to either approve or reject container legislation. The arguments entail jobs, energy and solid waste. These aspects are considered further in the following section on economics.

Source separation was discussed earlier. Suffice it to say that further advances are expected in the near term. Recently, a National Recycling Research Agenda Conference co-sponsored by the National Science Foundation and the Institute for Local Self Reliance took place which focused upon, among other topics, glass recycling. Some of the research results were incorporated in this document.

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The Eighties are expected to see further growth as the trend toward lighter materials in transportation continues. In this area, glass-plastic composites hold great promise as a future growth industry. Many glass manufacturers are now also diverging into plastics production.

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SECTION 6

ENVIRONMENTAL AND ECONOMIC EVALUATION

INTRODUCTION

This section presents a discussion of the environmental and economic impacts for those resource recovery techniques described and determined to be state-of-the-art for plastics and glass waste.

In the commercial and manufacturing segments, resource recovery activities have been straightforward. The economics are based on the material being of known composition and quality, and free of contamination. In particular, the economics of the plastics industry is very much dependent on the recycle of scrap (waste) internally or by sale. "Scrap" is usually reintroduced into the production stream either directly or "downstream" of the resin manufacturers. Through the recovery of plastic and glass wastes, adverse environmental and economic impacts are mitigated and beneficial impacts are realized.

In contrast, plastics and glass wastes from municipal sources are mixed with other wastes and are contaminated. They must then be separated from other solid wastes or at least concentrated into suitable fractions, homogenized, and decontaminated prior to any successful utilization. Sections 4 and 5 discussed the various methods for separating, recovering and reusing plastics and glass wastes. It is apparent that, at the present time, recycling from municipal sources is limited. For both plastic and glass cases, there exists a paucity of environmental and economic information. As a result, environmental and economic impacts are difficult to assess. Moreover, no existing commercial recovery system, other than certain pilot mechanical and source separation systems, recover plastics or glass from municipal sources as a sole product. Consequently, identification of specific impacts and costs is, at best, a most difficult proposition.

In view of the above discussion, the following sections will assess generalized economic and environmental impacts associated with the state-of-the-art in representative recovery systems that deal at least in part with plastic and/or glass wastes. Wherever possible, case studies will be utilized to provide data points.

PLASTICS WASTE RECOVERY IMPACTS

The state-of-the-art for plastics waste recovery from municipal wastes is in the developmental stage. Although no system(s) clearly outperform

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others, it appears that energy recovery utilizing solid wastes, with mixed plastic as one component of a combustible fraction, will be the most prevalent form of resource recovery. Systems for recovering selected plastics either through buy back or deposit systems are still considered an emerging technology and no environmental or economic information exists. The recycling of selected PVC scrap contaminated with copper and the PET bottle are promising. In any system, there will always be opportunity for recovery utilizing source separation. Current successful models were assessed in Section 4, but these methods are highly dependent on clear, segregated scrap, and technology is clearly unproven as to cost-effective separation of plastics into reusable individual types. Lower, secondary uses appear to hold future promise for recycling, but it depends on substitution of uses for material such as wood or concrete. At present, though, projected recovery rates are negligible from municipal refuse. In this framework, environmental and economic impacts can only be speculative.

Environmental Impacts of Plastics Waste Recovery

Combustion--

Combustion was assessed in Section 4 as the most viable means for tertiary recycling. Those systems which recover energy values from the organic matter in solid waste are: (1) refuse-fired incineration, (2) pyrolysis, and (3) refuse-derived fuel (RDF) production.

The environmental impact of recovering energy values from plastics contained in municipal solid waste is primarily limited to atmospheric emissions. The extent and type of emissions depend upon the thermal process employed and the composition of the solid waste being thermally heated.

The solid waste composition will markedly influence the quantity and quality of atmospheric emissions. Municipal solid waste streams vary from community to community throughout the United States; thus, only general estimates can be made as to potential atmospheric emissions due to plastics. Exact estimates are dependent on site specific conditions.

Several references discuss general environmental impacts for disposal of plastic in municipal solid waste streams. At best, these are rough estimates and as such must be regarded with caution. One in particular estimated emissions from the controlled combustion of plastics in solid waste. Table 18 indicates the projected emissions from contributions of plastics through the year 2,000 (77). These estimates were calculated on the basis of the estimated plastic percentages in the solid waste and emission factors for controlled air incinerators. These estimates do not include heat recovery and power generation, as will probably be the accepted practice in the future for incineration. Nevertheless, it is projected that the addition of a boiler to the incineration unit will not have significant effect on these emissions. These figures also do not allow for technological improvement in reducing emissions.

The impact of plastics upon the overall atmospheric emissions from burning refuse is difficult to quantify. Experimental evidence has indicated that burning of the three most widely used plastics -- polyethylene,

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TABLE 18. EMISSIONS FROM CONTROLLED COMBUSTION OF PLASTICS IN SOLID WASTE

Item	Year 1970	1975	1980	1985	1990	1995	2000
Waste burned, Tg[a] (10^6 ton)	13.4 (14.8)	16.8 (18.5)	20.7 (22.8)	28.5 (31.4)	36.6 (40.3)	44.1 (48.6)	51.3 (56.5)
Plastic content, percent	2.32	2.99	4.2	6.7	10.0	14.2	20.0
Plastic burned, Tg (10^6 ton)	0.31 0.34	0.50 0.55	0.87 0.96	1.9 2.1	3.6 4.0	6.3 6.9	10.3 11.3
CO emissions, Gg[b] (10^6 lb)	5.4 11.9	8.7 19.2	15.3 33.6	33.4 73.5	63.6 140	109.4 241	179.8 296
Particulates, Gg (10^6 lb)	2.3 5.1	3.7 8.2	6.5 14.3	14.2 31.3	27.1 59.6	46.8 103	76.3 168
Hydrocarbons, Gg (10^6 lb)	0.23 0.51	0.38 0.83	0.65 1.44	1.41 3.15	2.70 6.0	4.7 10.4	7.7 17.0

polystyrene, and polyvinyl chloride -- contributes insignificant emissions under properly maintained combustion conditions (78). Polyethylene melts early in the burning process, is completely consumed in any properly operated plant, and leaves minimal residues. The only byproducts are carbon dioxide and water. Polystyrene emits black smoke particles into the atmosphere when burned in the open air. However, in properly operated incinerators and boilers, this smoke is reduced and any particles would be captured effectively by control devices such as fabric filters, scrubbers, or electrostatic precipitators.

Some concern has risen over potential hydrogen chloride and vinyl chloride emissions from burning waste that contains chlorinated plastics such as poly vinyl chloride (PVC) and vinyl chloride. Both hydrogen chloride and vinyl chloride emissions could be potential health problems. The chloride emissions could also erode the metal surface within the furnace unit. In as much as new installations have not faced serious problems with this pollutant, it can be said that the impact of hydrogen and vinyl chloride emissions is minimal and can be effectively contained through proper equipment design and control systems, i.e. wet scrubbers.

Most PVC goes to long life application, and PVC in packaging is not projected to grow rapidly.

Secondary Products--

Of interest here is whether secondary products made from plastic waste represent potential pollutant sources, whether in the process or product. Most of these products, such as fence posts, tiles, plasticizers, paint extenders, etc., are too new for data to exist concerning their impact. The processes themselves are a different matter. Their health effects could be severe. However, due to the proprietary nature of processes recently developed data are lacking. Environmental impacts are at best only speculative as a result.

For example, where selected solvent extraction might be practical, water pollution and volatile emission will present hazards. According to a processor of mixed plastic wastes (primarily polyesters), air quality control on solvent/processes has reduced normal plastics-making emissions in half (79). However, the owner has stated that the process does not meet state regulations and the operation will have to close down and move to an area with less stringent pollution regulations.

There have been some problems related to workplace hazards and plastics recycling. However, it is supposed that any industrial process will have some workplace hazards. Pyrolysis of polyurethane will yield tolidine diisocyanate (TDI), a deadly toxic substance. Literature notes that plastic granulators used to regrind off-spec resin and other scrap have been developed which now meet OSHA noise standards of 90 dBA for any 8 hour shift (19).

Land impacts--

Land disposal of plastics has two major impacts: energy and volume. The disposal of plastics in landfill results in a loss of potential fuel. When placed in landfills, plastic has a certain resiliency that defies compaction, to a degree. Resistance to compaction enhances surface area of refuse exposed to pockets of water and allows differential settling and collection of gases (80).

Energy Recovery--

The heating value of plastics is high relative to other refuse components. In a properly controlled energy recovery operation, the plastics fraction will add to revenue derived from sale of energy products. Table 19 presents various heating values for plastics and other refuse components. This energy value will offset oil from foreign and domestic sources (81).

TABLE 19. HEATING VALUE FOR VARIOUS COMPONENTS IN SOLID WASTE

Type of waste	Heating value KJ/g	Heating value (Btu/lb)
Paper	1.76	(7,572)
Wood	20.0	(8,613)
Rags	17.8	(7,652)
Garbage	19.7	(8,484)
Coated fabric-rubber	25.6	(10,996)
Coated felt-vinyl	25.7	(11,054)
Coated fabric-vinyl	20.7	(8,899)
Polyethylene film	44.6	(19,161)
Foam-scrap	28.6	(12,283)
Tape-resin-covered glass	18.4	(7,907)
Fabric-nylon	30.7	(13,202)
Vinyl scrap	26.6	(11,428)
Glass	0	0
Metal	0	0
Stone, inorganics	0	0

There has also been some concern about the energy balance related to plastic versus renewable resources, and plastic versus returnable containers. An energy balance for these two issues was developed by the plastic industry and was presented in literature in January 1979. Tables 20 and 21 present these data (82).

TABLE 20. ENVIRONMENTAL IMPACT SUMMARY (2 LITER BOTTLES)

System	Resources consumed (lb/unit)	Energy consumed (Btu/oz)	Waste (lb/unit)	Empty weight in (cartons lb/unit)
A. 1 Way				
PET	0.82	230/185*	0.45	0.33
Glass	3.41	470	4.15	2.74
B. Refillable				
1. Glass (5)	1.07	180	1.20	3.44
2. Glass (10)	0.71	120	0.70	3.44

* 185 Btu if burned as fuel

TABLE 21. ENVIRONMENTAL IMPACT COMPARISON (PER LB PER 100,000 SQ. FT.)

	Coated cellophane	LdPE film
Material consumed lb.		
raw materials	2000	535
fuel	3450	715
Total	5450	1250
Waste generated, lb.		
liquid	1300	
solid	650	60
atmospheric	320	40
Total	2270	100
Energy million Btu		
Feedstock	10	10
Manufacturing/transport	45	15
Total	55	25
Recoverable	5	10
Net	50	15

In a system where refillables are returned fewer times, the one-way PET bottle shows a favorable energy and resource balance. If trips for the refillables increase to 15 - 20 times, the impact of the glass greatly diminishes (82).

Economic Impacts of Plastics Waste Recovery

Many factors dictate the economic feasibility for any system. For plastic waste resource recovery, one of the major considerations appears to be establishment of readily available markets for recovered materials whether for energy value or secondary materials.

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The fact that plastic recovery systems are only now being utilized on a commercial basis compounds the difficulties of conducting an economic analysis.

For plastic waste generated during the manufacturing of plastics, the capital-related expenses required to conduct recycling are offset by material savings. Literature has identified a mathematical model for determining economic viability. This model is shown below:

Cost of material per unit of product produced (19):

$$M_1 = \frac{P(1-R) - X(S-R)}{1-(S+L)}$$

M = \$/lb; mat'l cost/lb. of salable product
P = Virgin resin cost \$/lb
X = Salvage value of scrap \$/lb
S = Scrap and waste as fraction of total feed
R = Recycled scrap as fraction of total feed
L = Non-recoverable as fraction of total feed

To ensure that maximum profits can be realized from purchased materials, manufacturers strive to reduce waste to a minimum. Some plastic scrap which is not reprocessed internally by primary polymer producers and fabricators is sold to scrap dealers or processors. The scrap is attractive from an economic viewpoint, since it creates new business opportunities and reduces raw material costs. For example, one company is reported to purchase fairly clean scrap polyethylene film and bags, and rework it. The recovered granulated pellets are added to virgin input in the ratio of five to ten percent scrap. The cost of recovered polyethylene, including the purchase of scrap and processing, is said to be less than 50 percent for the virgin material (7). From another source, it was reported that urethane foam recovered from scrap automobiles would return about three times the recovery costs when the material is sold and that landfilling the same urethane could cost up to 20 times the recovery costs (7). Another example was sited for recovery of rigid urethane by conversion to polyol. This recovery process was economically sound since the effective cost of the reprocessed polyol was about two-thirds the cost of virgin polyol (7).

While inplant recycling is an established fact, once the plastic waste becomes part of the municipal waste stream, the economic incentives for recovery are generally insufficient to overcome the costs of recovery. Inplant plastic scrap is generally uncontaminated and of known composition. As such, it is prudent business procedure to reuse or convert waste to other products. However, when the plastics are mixed with other wastes, it is almost impossible to recover pure plastics. Even if it was possible to recover relatively uncontaminated plastic fractions, the problems of incompatability, uncontrolled feed quality and existing market conditions would limit use of these products. The cost of separating plastics from other refuse would also be excessive in view of the relatively small amounts of plastics found in the overall municipal

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waste stream. For any recovered material, the recovery costs must not exceed the virgin material cost for whatever item it is replacing. Actually the selling price of the recovered material would have to be considerably less than that of raw materials in order to become attractive to a potential customer, especially in view of possible impurities in the recovered material. This is one reason why most potentially feasible products composed of recycled plastic are secondary in origin and distribution, e.g., they have nothing to do with primary plastic manufacturing, but are an entirely different industry. An exception was the reported PVC scrap recycling by Western Electric.

A recent phenomenon concerned bottle deposit legislation in Michigan. It appears that the deposits on 32 ounce plastic containers are encouraging their return to producers (83). This clean scrap has the advantage of being uniform and of recent age. Hence, it should be usable in the production of secondary products. Most recently, a glass processor in New England has begun buying back plastic PET bottles (84).

In connection with the PET bottle, Goodyear Tire and Rubber Co. has published economic data on a 10 mm lb/yr (design, not actual) facility. The following assumptions were used:

- Product is clear polyester flake
- Labor requirements are 3 people @ $40/hr
- System capacity of 10 mm lbs/yr @ 6,000 hrs per yr

A facility output was cost-estimated at $0.18 per lb. Capital cost was estimated at $700,000, exclusive of buildings. Data are presented in Tables 22 through 26 (37).

TABLE 22. RAW MATERIAL COST

	$/Lb
Purchase granulated polyester bottles..........	0.03
Transportation	0.05
Subtotal	0.08

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TABLE 23. CAPITAL COST

Equipment (Table I)	$230,000
Installation @ 100%	230,000
Subtotal	460,000
Engineering @ 10%	46,000
Shipping @ 10%	46,000
Contingency @ 25%	115,000
Total Capital Cost	$667,000

TABLE 24. PROCESSING COST

	$/Hr.
Labor and Overhead	
3.0 men @ $40/man hr	120.00
Rent (9,000 sq. ft., includes storage) 9,000 sq. ft. @ $3/sq. ft. yr./6,000 hr./yr	4.50
Depreciation 10 yr. straight line	11.12
$\frac{\$667,000}{10\text{ yr.}}$ = $67,700/yr./6,000 hr./yr.	
Utilities	
Electricity	
(110 HP/hr) (.746 $\frac{KW}{HP}$) ($0.05/kwh) (1/.6) motor efficiency	6.84
Heating Oil (1,500,000 btu/hr) (1/140,000 btu/gal.) ($.80/gal	8.57
Makeup water (500 gal/hr) ($3.00/10,000 gal)	0.15
Total processing cost ($/hr)	151.18
$\frac{\$151/hr}{1750\text{ lb/hr}}$ = $0.086/lb.	
Packaging cost $0.015/lb.	

TABLE 25. TOTAL COST TO RECYCLE PET BOTTLES

	$/Lb.
Raw Materials	0.08
Processing Cost	0.086
Packaging Cost	0.015
	$0.181

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TABLE 26. RECYCLE EQUIPMENT LIST AND COST* (10 MM LB/YR CAPACITY)

Granulator with feed conveyor and air exhaust w/cyclone	$ 40,000
In line magnets	1.500
Fluidized bed air separator	25,000
Eddy current separator	46,000
Float separator (liquid cyclones)	35,000
Washing machine (drying zone included)	50,000
Metal detector	7,500
Misc. conveyors and handling equipment	25,000
	$230,000

*Except for eddy current separator, all costs are actual quotes which have been adjusted upward for inflation. Eddy current separator cost is based on quotation for smaller capacity unit and then has been adjusted by 0.6 rule for capital cost estimation.

As previously discussed, energy value recovery from mixed solid waste appears economically favorable in terms of energy budgets and site specific shortages. Even so, these systems rely on other organics in addition to plastics. Thus, an economic analysis for plastic utilization in thermal recovery systems cannot be made. However, it can be stated that polyethylene will release the same number of Btu's as an equivalent weight of fuel oil (35).

Overall economic generalizations can be made regarding energy value recovery from municipal solid waste systems. Significant capital expenditures are required to construct facilities that recover both materials and energy. The materials recovery helps relieve a portion of the economic burden since available markets exist for recoverable materials such as iron, aluminum, and, to a certain extent, glass. In adddition, limited markets exist for energy values recovered, depending on the geographical location.

GLASS WASTE RECOVERY IMPACTS

Resource recovery for glass has been discussed in Section 5. As with plastics, efforts to recover scrap glass generated during manufacturing operations are maximized. Community recycling activities do provide a limited return for post-consumer glass (almost entirely container glass); however, total participation throughout the United States is not practiced and quantities recovered represent only a small fraction of the total glass waste. According to EPA, 4 percent of the glass fraction is recycled from municipal solid waste (85).

Efforts to mechanically recover glass from municipal wastes have been limited to pilot scale operations. Only source separation systems recover glass as a major product from municipal solid waste.

The environmental and economic impacts associated with glass recovery are, therefore, difficult to assess. This is compounded by the fact that recycling methods such as community-sponsored recovery and in house industrial recovery practices are so dispersed geographically that insufficient data exist to accurately assess any impacts. Nevertheless, an attempt will be made to evaluate some of the more promising recovery techniques and their generalized impacts.

Environmental Impacts of Glass Recovery

Glass waste from the glass manufacturing industry and in many commercial establishments is routinely collected and used (or sold) as cullet for reuse in the manufacturing process. Adverse environmental impacts associated with these practices are minimal.

Environmental impacts associated with glass waste recovery from municipal refuse are mostly beneficial. Major impacts are listed below:

- lessened impacts from extractive industry operations
- diverted landfill volume
- reduced traffic from hauling
- reduced air emissions from glass manufacture and the potential of emission offset for cullet reuse.
- energy conservation.

By increasing recyclable volumes into batch processes, a considerable reduction could indirectly occur in environmental emissions. Virgin materials extraction and virgin materials processing requires a considerable amount of energy and causes limited environmental degradation. In extraction, land disruption occurs and there is increased potential for silt introduction into waterways (2). In processing, dust, noise, tailings, sludges, and suspended and dissolved solids in water (2) are generated.

The introduction of an inert material such as glass into landfill systems poses no environmental pollution problem for ground water quality. However, by continuing its introduction into scarce landfill, especially Class I (classified for hazardous waste), glass waste acts as a potential competitor for limited space with items that should have higher priority.

The hauling of glass to recycling operations occurs by rail, car and truck. Increasing glass cullet reuse would undoubtedly increase emissions associated with the transportation sectors. However, it should be noted that when glass is collected for landfill disposal, considerable emissions occur. There should be some proportionate drop in refuse hauling emissions as glass is extracted.

There have been investigations (40), that confirm the relationship between cullet reintroduction into production and lowering of air emissions. Raw virgin materials used in glass manufacture go through complex chemical reactions resulting in the release of gases and particulates. Cullet, having once undergone these reactions, will not add to emissions (86). Also, it has been documented that cullet lowers the

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melting temperature. By doing so, emissions associated with higher temperatures (such as NO_x) are mitigated. One glass manufacturer in California has reported that increasing cullet usage has allowed his operation to meet air quality regulations.

With regard to energy, cullet introduced into the batch at a controlled rate can reduce melting energy by about 1/4 to 1/3 of a percent per 1 percent of cullet added. This formula is applicable at charges up to 50 percent cullet. Anticipated energy savings could range as high as 11-12 percent per batch (87-90). While detailed energy studies have been conducted for glass container manufacture in Europe, and limited studies in the U.S., no studies have been performed for other glass production sectors.

The EPA in the 5-volume study on the Marblehead and Somerville, Massachusetts source separation programs conducted analyses of energy consumption-savings for three alternative scenarios: landfill, transfer station, and a combination system involving source separation. Each alternative scenario was separated into 4 independent steps: collection, processing, transportation, and recycling. It was found that the existing source separation program returns about 1.6 million Btu/ton of solid waste. Of the alternatives, the combined system had the highest energy return. On the energy-used versus -saved analysis for the Marblehead source separation program, it was found that 151×10^3 Btu/ton was expended for a return of 770×10^3 Btu/ton. This nets a return of 619×10^3 Btu/ton recycled glass (91).

It is important to note here that considerable discussion exists on the relative advantages and disadvantages of returnable bottles. Reuse enthusiasts maintain that while some energy is saved in manufacture using cullet, more energy savings are realized from utilizing returnables. Those countries that practice reuse of glass containers do show smaller percentages of glass in the waste load and less roadside litter, based on evaluations of different systems (92).

Impacts of reuse systems would appear to be mainly focused in the economic sector, though bottle washing should increase emissions in wastewater (primarily food stuffs and organics), decrease landfill burden, and save energy.

Economics of Glass Waste

No definitive study exists detailing the specific economics of glass recovery from municipal solid wastes. There are data, though, which identify various cost factors and which assign values on a case-by-case basis. The goal of this subsection, therefore, is to conduct limited economic analysis by defining cost elements and centers, assigning appropriate cost values where available, and assessing cost benefits (e.g., costs versus revenues).

Source separation and mechanical operations are dependent, to a certain extent, on glass recovery. This aspect has been brought up in the perennial "deposit-no deposit" debates where "no deposit" supporters stress that

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removal of glass from the wastestream by container legislation would "sound the death knell" of source separation activities for recycling.

On the other hand, a recent EPA report performed for the Marblehead and Somerville, MA source separation curbside collection program speculated that since half of the source separated glass and metal were beverage containers potentially subject to container deposit legislation, there might be a corresponding reduction in the need for collection equipment, labor and collection frequency. Hence, beverage container legislation need not substantially decrease the net revenues from source separation programs (93). One aspect, though, that relates to program revenue is variability in composition. Container glass was found to vary little over the long-term in relative percentage of the recyclable wastestream. Other materials fluctuated more (93). This might mean that removal of a stable collectible would cause revenue loss and increase other costs due to more extreme variations in loadings.

Cost Elements--

Costs can be defined for specific operational modes of recycling. For example, the cost of transporting products to market constitutes one element. Cost elements are slightly different for intermediate processors and community recycling centers. For all programs, though, generalized cost elements include:

- collection
- processing and storage
- transportation
- marketing
- administration

Cost can vary from area to area, and from type of technology to marketing conditions and products. The cost factors which determine the element costs are:

- labor
- utilities and fuel
- capital expense and amortization
- maintenance
- overhead (insurance, etc.)
- building modifications
- publicitiy

While no specific study has detailed all these elements in a comprehensive economic analysis, there have been individual reports detailing one or more of selected factors.

Costs--

Representative costs for dropoff system structures were prepared. In that short study, estimated costs per ton were developed on a comparative basis for glass recycling. Using two studies and two estimates, costs were assigned to citizen preparation, public payment, processing equipment, labor, construction, storage, transportation and administration. Costs ranged from $15/ton to $37/ton. The two largest sub elements were labor and transportation. Table 27 presents these representative costs (94).

TABLE 27. REPRESENTATIVE DROPOFF SYSTEM COST STRUCTURES ($/TON)

	ICF[1]	SCS[2]	SRI[3]	SEH[4]
Citizen level				
Implicit cost of material preparation and delivery	108.00	-	-	-
Recycling center level				
-Payment to the public	10.00	-	10.00	10.00
-Processing equipment	-	-	3.00	2.00
-Labor	-	17.00	10.00	10.00
-Building modification	-	-	4.00	-
-Storage	-	-	0.80	2.00
-Transportation	5.00-10.00	16.00	7.00	10.00
-Admin. & overhead	-	-	1.00	3.00
	15.-20.00	33.00	35.80	37.00

[1] ICF Incorporated; "Estimated of Elasticities of Secondary Material Substitution and Supply," January 31, 1979. Gross cost estimates excluding handling and processing, building, admin. costs and profits.

[2] SCS Engineers, Inc.; Analysis of Source Separate Collection of Recyclable Solid Waste - Collection Center Studies, 1974, Excludes profit.

[3] Conversation with Don Kneass; Seattle Recycling, Inc.; Dec. 3, 1979. Excludes profit.

[4] Estimates prepared by Steve Howard, Glass Packaging Institute.

In a concurrent analysis of curbside collection programs (95), representative costs were developed based on all recyclables collected. It showed a net gain in the Marblehead, MA program, but a net loss in four other programs. These costs were assigned on the basis of actual processing per ton, disposal savings per ton, and revenue per ton. Table 28 presents data from the analysis.

TABLE 28. REPRESENTATIVE CURBSIDE COLLECTION COST STRUCTURE*

	Ton recovered month	Actual cost/ton	Disposal savings/ton	Revenue/ ton	Net gain (loss)/ton
San Luis Obispo, CA	75.0	44.50	-	25.00	(19.50)
Somerville, MA	171.0	52.06	9.40	7.12	(35.54)
Marblehead, MA	148.0	23.30	18.95	11.78	7.43
Andover, MA	101.0	22.92	9.00	13.37	(0.55)
Newton, MA	179.0	87.19	14.84	9.10	(64.05)
Unweighted average		46.15	10.44	13.27	(22.47)

*ICF Incorporated; Estimates of the Elasticities of Secondary Material Substitutes and Supply," January 31, 1979

Another analysis performed by the California Solid Waste Management Board (96) detailed costs/benefits on a generalized basis for buy back and donation collection centers. It noted the subsidy programs available to recyclers: the SB650 grant program and Comprehensive Employment Training Act (CETA). In California, about 100 centers are operating. Capacity ranges from 5 to 50 tons per month. Each center is unique in staffing, material processing, storage and other cost elements. It is difficult to arrive at an average cost. The CSWMB developed a model center based on the following assumptions:

- Site was donated except for utilities and fencing
- Labor for first 10 tons is donated; subsequent amounts are costed at $4.07/hr
- It requires about 1.5 hours to process each ton for a labor cost rate of about $6.03/ton

Item	% by weight received	Price/ton (1978)
Aluminum	1.1	340
Newsprint	61.2	15
Glass	25.9	15
Ferrous	11.8	0

The average revenue would appear to be $16.80/ton based on 1978 dollars. The CSWMB then calculated for various tonnages, costs and benefits on a monthly basis. The obvious break-even point would be 25 tons/month. In this scenario, glass is an important and stable component inasmuch as newspaper fluctuates widely in market value.

Tons/month	$Cost/month	$Revenue/month	$Profit/month	$Revenue/ton
10	224	168	-76	-7.60
20	377	337	-40	-2.00
30	462	504	42	1.40
40	598	672	74	1.85
50	711	840	129	2.58

A generalized model was developed:

Profit or loss per month = (tons per month x $5.24) - $131.40

This type of analysis was also performed for buy back operations. Such an operation often receives up to 5 tons of recyclables per day. To speed up transactions, there has recently been a move to automate accounting of payback credits. While this procedure can be cost-saving, it forces profit centers to meet (in California) public weighmaster's code which is quite stringent (96). For this analysis, CSWMB assumed:

- center is operated for profit
- 40 minutes is required to process each ton
- two scales are in use (aluminum and glass)

Table 29 presents buy back center materials and prices.

TABLE 29. BUY BACK CENTER MATERIALS AND PRICES

Item	Percentage by weight	Cost/ton ($1978)	Revenue/ton ($1978)	Processing/ton ($1978)
Aluminum	9.0	340	640	300
Newsprint	77.6	15	35	20
Glass	10.2	15	18	3
Ferrous	3.2	0	0	0

The average recyclables revenue is $43/ton. Based on these costs and prices, the following was determined:

Tons/month	$Cost/month	$Revenue/month	$Profit/month	$Revenue/ton
50	5463	2141	-3332	-66.44
100	5598	4283	-1315	-13.15
200	5875	8566	2691	13.46
300	7177	12849	5672	18.91
400	7454	17132	9678	24.20
500	8756	21415	12659	25.32

The breakeven point is around 135 tons/month. From Table 29 it appears that glass is a marginal buyback operation. These costs, for both buyback and volunteer, appear to exclude public relations, administration, any external costs, and transportation costs. A model was developed:

Profit/loss = tons/month x $35.57 - $4,846

A true economic picture of recycling centers is difficult to obtain. "Hidden" costs can include volunteer or low-paid labor, free materials, free land, government grants, etc. As noted earlier, some programs have access to CETA employees (96). On the other hand, there are intangible benefits which cannot be included on a ledger including the benefits in education and diverted disposal. Therefore, in an economic study done by EPA, the costs per ton of recycled material varied from $169 per ton after disposal credit to a net $6 per ton excluding landfill credit (97).

The CSWMB also developed some costs for curbside collection operations. The reference noted that more handling increases costs (96). Handling is the result of off loadings, transfer, processing, extra storage and transportation. Costs of curbside collection, as already noted in Table 28, can range as high as $40/ton. CSWMB estimated that breakeven would be possible for comprehensive programs if a subsidy was required (e.g., a slight collection charge, for example.)

In order to develop a generalized cost model, a "theoretical composite system" was employed. It was assumed that one hour was necessary for processing each ton collected, and that one vehicle and six storage bins were required for each 100 tons/month collected. Aluminum was estimated to be 13 percent of the recyclable material collected at a price per ton of $640. Newsprint was estimated at 54.8 percent by weight with a corresponding price/ton of $35. Glass and ferrous materials were 34.8 percent and 9.1 percent by weight, respectively, with associated revenues of $18/ton and $0/ton, respectively. These are based on 1978 dollars. CSWMB estimated monthly costs and benefits as follows:

Tons/month	$Cost/month	$Revenue/month	$Profit/month	$Revenue/ton
100	6987	3382	-3605	-36.05
200	9942	6674	-3268	-16.34
300	11877	10146	1731	5.77
400	14838	13528	1310	3.28
500	17440	16910	530	1.06
600	20456	20292	164	0.03

The breakeven point is greater than 600 tons/month. A multimaterial program could be successful, though, if a subsidy was provided, material revenue were to increase significantly, or aluminum were to be separately purchased in a buy back program (96).

A model was developed:

Profit or loss = tons/month x $23.70 - $4,369

In a study performed by EPA of the Franklin, Ohio resource recovery plant, the economics of glass recovery was assessed at the 50 TPD level (68). Projections were then made at the 500 TPD and 1000 TPD levels using 1975 dollars. Cost projection included facility amortization, operating and maintenance costs, and glass, ferrous and aluminum sales. The study concluded that for multimedia operation the system was economically viable but for glass recovery alone it was not feasible. The proportion of the revenues generated are also important in this respect. One-third of the projected revenues would be attributable to glass. Yet over half the costs associated with the plant are associated with glass recovery. This is because color sorting and glass processing is highly capital and energy intensive.

A critical assumption of the study was that at larger installations, ceramic contamination could be reduced to meet stringent industry specifications or that the glass industry would accept a higher level of contamination than was accepted at the time. (These specifications have not been relaxed sufficiently). Table 30 presents study cost projections for the Franklin plant (98).

Another study currently under draft for EPA, assessed costs of collection, processing, storage and transportation equipment for source separation (99). Two programs, in Grand Rapids, MI and Seattle, WA, were evaluated for selected equipment associated with glass recovery. Recycling Unlimited, Inc. of Grand Rapids owns a glass crusher and glass conveyor. The conveyor was estimated at $5,000. No cost was quoted for the crusher. In Seattle, the Seattle Recycling Program owned a glass crusher and conveyor system. The crusher (capacity of 4000 lbs per hour) was costed at $1,040 with $500 installation. The conveyor system was costed at $250 with a $500 installation and $250 modification.

In a project for the CSWMB, complete costs of developing an intermediate processing operation (excluding vehicles and building) were estimated to be $469,000 (100). Table 31 presents a summary of these costs in 1979 dollars for the 650 ton per month cullet plant.

Several estimates of transportation costs were made, and they are summarized below (101):

$1.00/ton mile (local)
$ .75/ton mile (long haul)

The costs of glass recycling programs are variable; they are highly dependent on the market, location, FOB point, whether equipment is supplied, the product mix-contamination level, and the volume. For grass roots programs, prices have ranged from $10-$30/ton. Highest prices are based on color sorting of flint and for FOB glass plant or processor. For intermediate processors, prices range from $20-$50/ton normally, with $60-100/ton not unusual (102).

Economic Analysis--

There are other institutional and market factors that impact on the economic recovery of glass from municipal solid waste. The following discussion covers these factors and then summarizes costs versus benefits.

For all levels of recycling, the degree of cullet usage has to be partially dependent on raw material supply. Raw material costs have remained fairly static in the past and with the discovery of new silica sand deposits in California should remain so in the future. It is estimated, therefore, that clean cullet will continue to have a value consistent with virgin materials.

TABLE 30. COST PROJECTIONS FOR A FRANKLIN, OHIO GLASS RECOVERY SUBSYSTEM AT 500 AND 1000 TON PER DAY RESOURCE RECOVERY PLANTS (BASED ON 1975 COSTS)

Category	500 TPD plant	1000 TPD plant
Capital cost of glass recovery subsystem	$1,437,000 (54 TPD throughput)	$2,430,000 (108 TPD throughput
Expenses	$/ton total raw SW delivered to the recovery plant	$/ton total raw SW delivered to the recovery plant
Operating labor	1.05	.53
Maintenance	.64	.47
Supplies and misc.	.16	.12
Utilities	.16	.11
Subtotal	$2.01	$1.23
Facility amortization Interest (20 years at 9%)	$1.45	$1.07
Total expenses	$3.46/ton	$2.30/ton
Income		
Magnetic sales (@ $25/T)	.25	.25
Aluminum sales (@ $300/T)	1.95	1.95
Glass (@ $20/T)*	.58	.58
Total income	2.78/ton	$2.78/ton
Net cost per ton (profit)	.68/ton	$(.48/ton)

TABLE 31. PROJECTED LISTING AND COSTS FOR A GLASS PROCESSING OPERATION AT 650 TONS/MONTH

Item	#	$	
		Amount	Cost
Processing Equipment:			
Magnet/system	1	20,000	20,000
Hopper	1	3,000	3,000
Vibrating feeder	1	2,000	2,000
Screens	.6	15,000	15,000
Shaker	2		
Crusher	1	72,000	72,000
Storage Equipment:			
20 cu yd bins	60	2,500	$150,000
Transfer Equipment:			
Tractor-trailer	1	50,000	50,000
Conveyor belts	5	4,000	2,000
Miscellaneous:			
Skiploader	1	35,000	35,000
Safety equipment			
- dust collector		25,000	25,000
- personnel protection			
Reserve motors and belts		10,000	10,000
Installation:			
Electrical installation		15,000	15,000
Physical installation		15,000	15,000
Engineering		10,000	10,000
Site Improvements:			
Bunkers	8	3,375	27,000
Total			$469,000

The ability of cullet collectors and processors to meet specifications continues to be a major factor in economics. Where a processor is able to procure properly sized and adequate equipment/storage-processing space, color specification is not a problem.

The freight rate is more expensive for recycled goods than for virgin products and acts as a deterrent to increased glass recycling. Coupled with stringent specifications, freight rates can make transfer an extremely costly proposition. As an example, one processor shipped clean cullet to a manufacturer, who found stones among the cullet, thereby rejecting the load. While being transported in open top "train boxes", the shipment had evidently been vandalized. This one occurrence, though, cost the processor over $7,000, a cost he was unable to recoup.

Two areas which promise some relief for sellers of cullet are foreign export markets and secondary products manufacture. If secondary markets can be found in sufficient quantity to allow simpler collection without regard for color segregation, recycling economics can improve.

SPECIFIC ECONOMIC ISSUES

There are a few additional economic issues which relate to plastic and glass waste recovery. These include:

- Employment and other socio-economic impacts
- Litter tax and reuse strategies
- Obstacles to increased recycling
- Economic development
- Diversion credits

Employment and Other Socio-Economic Impacts

Recovery of waste materials has positive employment and social impact. In the case of collection centers, such programs directly involve citizens in solid waste management activities. As a result, it can help the public understand the problems of solid waste management and achieve certain levels of conservation and litter abatement (55). An important consideration is that source separation-collection centers are labor-intensive. Many programs are initiated with the goal being to hire the handicapped or difficult to employ individuals (55).

Recycling industries are basically "conservation of energy industries" which reduce pollutant generation and material usage. It is theorized that these industries will serve as major foci of investment and urban redevelopment strategies in the near future (1). Not only will employment aspects be served, but additional market capacity will encourage further recovery of waste materials. This has a direct impact on the quantity of material being landfilled or otherwise disposed.

Litter tax and reuse strategies

Although this study does not address in detail waste reduction measures, it is important to discuss selected aspects which impact recovery of plastics and glass. Aspects of importance to recycling include:

- Implementation of funding/grant programs to encourage resource recovery
- Impact on the composition of the wastestream, and
- Increased recovery opportunities

In some states, "bottle bill" opponents have supported "litter tax" measures designed to tax litter generators or those who produce items that become litter, a small amount. This levy is then collected and added to a fund that may be made available to anti-litter programs and "recycling" programs. In California, a "litter tax" program has been in effect for two years at this writing. Over $5 million has been awarded to waste recovery programs for developmental activities. The program will be operational for another 3 years (76). This litter tax program has effectively defused bottle bill proponent efforts.

Waste reduction activities have had a degree of impact on the composition of the wastestream. According to data from Oregon, metal containers have been reduced, and glass has become a larger component of the wastestream (83). In another study in Michigian, it was found that metal containers were initially reduced, but within a year had increased although not to levels prior to bottle bill enactment (83).

Reuse measures do provide increased recovery opportunities. For example, in Michigan, PET two liter containers are being returned through the deposit system (83). PET is being recycled because the reuse system ensures a consistent and clean recyclable component. As PET is the only plastic beverage container, there is currently no major problem of compatibility of plastics. The major problems arise with the PET bottle contaminants, e.g., aluminum caps, paper labeling, thermoformed bases, and the different colors used (36).

Obstacles to Recycling

Current obstacles exist which inhibit increased glass and plastic recycling. One obstacle is the general price differential between virgin and recycled materials. Virgin materials have been cheaper in the U.S. because natural resources have been plentiful; because public policies favor virgin materials and environmental and other social costs (externalities) have been omitted from the price.

Federal Land Usage--

One obstacle is public policy on Federal land usage. Virgin material extractors, for example, gain competitive advantage from the resources and technical and scientific assistance of a number of supportive Federal agencies (103).

Tax Structures--

Tax structures generally favor virgin material processors. Over the years, the Federal government has developed tax policies that favor extractive industries. For example, capital costs incurred in exploring and bringing mineral deposits (glass silica) into production may be deducted as current expenses rather than amortized over the useful life of the property. Also, the costs of development are deductible after a commercial mineral is established. While it is true that at one time it was necessary to quickly and comprehensively exploit our resources, it is not necessarily true today. Incentives to explore and develop virgin materials retard demand for investment in recycling (103).

The theoretical basis for depletion allowances is that the course of exploitation of resources results in a wasting of assets. Extractive industries may choose between two kinds of depletion allowances. Under cost depletion allowances, industries can deduct capital costs over the productive life of the site in a manner similar to depreciation. Under percentage depletion allowances, industries may deduct costs immediately at the percentage allowed by law from gross revenue, but not to exceed 50 percent of net income where percentage depletion exceeds cost depletion (103).

The impact of tax structures and policies on the price relationship between virgin and recyclable materials is not fully understood. Undeniably, the extractive industries do pay less in taxes than manufacturing industries as a percent of total income (103). What impact removal of these policies and structures would precipitate is also unknown. What is known is that the special conditions given to extractive industries places recycling at a disadvantage.

Railroad Freight Rate Discrimination--

Transportation typically accounts for a very large fraction of the delivered cost of materials. Ideally, all materials would be charged costs that relate to the actual cost of hauling. However, in practice, various commodities and shippers are charged rates that differ, a condition referred to by many as freight rate "discrimination" (2). The U.S. Resource Conservation Committee (RCC) in a recent study found that freight rates are discriminatory against waste paper, glass cullet and scrap copper. Substantial and systematic rate differentials have been held by Congress, the U.S. EPA, the secondary materials industry and the U.S. Supreme Court to contribute to inefficient relocation of resources and to work against resource conservation. Currently, the Interstate Commerce Commission (ICC) is under litigation to revise their rates relative to scrap materials to, in effect, equalize freight rates.

Economic Development

There are two aspects of importance with regard to specific economic issues. These two aspects are: (1) economy of scale and, (2) secondary products development investment possibilities. The Glass Packaging Institute (formerly the Glass Containers Manufacturers Institute) has been sponsoring research into these two areas.

Traditionally, and as described earlier under Sections 3 and 5, the primary use for reclaimed glass is in the manufacture of new containers. However, this is not always feasible or practical especially where extensive mixing of cullet and contaminants occur (necessitating high costs of upgrading) and where transportation costs inhibit purchase of cullet. In all cases, where the cost of the cullet exceeds the cost of virgin materials, the primary markets will utilize virgin materials.

The need for development of secondary product markets independent of, in many cases, artifically low-cost, virgin materials, is becoming increasingly urgent as solid waste management enters an era of large-scale salvage. While many processes are technically feasible, only recently have economics improved to a point where secondary product development provides a competitive return on investment.

Economy of Scale--

An area of importance is the apparent reversal of trend from construction of larger, regional-type projects toward smaller, local and community-scaled industries. The impetus behind this is partially explained by the following:

- The need to provide local employment.
- The ready availability of waste resources for utilization.
- Reduced capital requirements for start up, research, operation and construction.

Section 5 contained a discussion of a smaller scale fiberglass plant in Canada which was constructed for a total investment of $10 million. At 11,000 tons/year, or approximately 30 tons/day, such a facility is feasible for smaller communities to attract investment, gain employment and provide a market for a glass wastestream.

GPI evaluated the potential for the commercialization of glass rubble building panels (104). These constructed flat panels produced by vibro--compaction techniques measure up to 10 feet x 4 feet x 4 feet, and weigh up to 1,900 lbs. The finished product would typically be composed of 94 percent ground waste glass, and the remainder a composite of clay and demolition rubble. Various complex sizes and shapes can be made, with ultimate usage as decoration or structural application. The immediate competition is with brick and precast concrete panels for structural application. Decorative panels must compete with rock, marble, mosaic, stucco, and glass-plastic composite panels (104).

Under economic analysis, it was determined that investment and development of these panels as an industry is closely keyed to "carefully defined (geographic) areas at a carefully determined scale of operation." Manufacturing costs range from $1 per sq. ft. for small-scale operations to $0.80 per sq. ft. for larger operations which are competive with alternative products. Wall panels made from "virgin" materials are currently being produced in more than 200 different plants within the U.S., reflecting a strong local nature of the business. Most of the operational and successful plants are located within 70 miles of their immediate market (104).

Under a similar investigation, mineral wool insulation utilizing waste glass was evaluated for technical and economic feasibility (105). Potential products which utilize up to 50 percent cullet include insulation batts and blankets, blowing wool, and high temperature felt insulation. Benefits to the manufacturer include:

- Permits significant shortcut in manufacturing by bypassing the conversion of silica sand and chemicals to the glass feedstock state.
- Useful for up to 1200 F temperature, which represents a 50 percent increase in use.
- Costs less to manufacture

Contaminants found in waste glass, though, (stones, etc.) can significantly impair a mineral wool process by plugging the "spinner".

Estimated capital requirements (incorporating a 100 percent inflation factor for 1971 figures) for an 18 ton/day facility is shown in Table 32.

TABLE 32. ESTIMATED CAPITAL REQUIREMENTS
FOR 18 TON/DAY GLASS WOOL PLANT

Category	$
A. Amortized investment	
Engineering, research and development	100,000
Start up	200,000
Subtotal A	300,000
B. Fixed investment	
Structures and improvements	260,000
Machinery and equipment	580,000
Subtotal B	840,000
C. Recoverable investment	
Land	80,000
Working capital	450,000
Total recoverable investment	$ 530,000
Total capital requirement	$1,670,000
D. Capital requirement per ton/day capacity*	$ 92,777

*250 days per year operation

The total manufacturing cost for the 18 ton/day operation is between $187.50 and $300.00 per ton. This range is acceptably within the limits of current glass wool prices (105).

Secondary Materials Development Opportunities--

Regardless of the potential for small-scale enterprises, there exists a potential for industrial development utilizing materials derived from municipal waste. GCMI has investigated several potential waste utilization enterprises, however, all have been related to low specification applications which could utilize glass derived from resource recovery. These enterprises include:

- Manufacturing ceramic tile with waste glass and animal excreta.
- Manufacturing terrazo with waste glass aggregate.
- Manufacturing foamed glass construction materials made with waste glass and animal excreta.
- Manufacturing slurry seal with waste glass aggregate.

Ceramic Tile--

Data on capital and manufacturing costs show a relatively low cost per unit produced. Tile produced from virgin material costs from $0.18 to $0.65 per square foot to produce. Total manufacturing costs, excluding capital costs, averaged $0.131 per square foot for waste-derived tile (106).

Terrazo--

Terrazo made with glass waste competes with more expensive marble. At any volume, material costs offset production costs for terrazo, thereby allowing a highly competitive price for the finished product (107).

Foamed Glass Construction Materials--

Total manufacturing costs of $0.41 per board feet compare favorably with virgin material-derived products. The demand for insulating board is expected to grow at an annual rate of 5 percent (108).

Slurry Seal--

The addition of waste glass to liquified asphalt can be used on road surfaces. Certain technical problems remain with adhesion to road surfaces. Extensive processing adds greatly to the cost of the rendered product (109).

Diverted Disposal Values

Materials diverted by source separation activities have a diverted disposal value. Although not necessarily credited to a center, the value should be considered when assessing program viability.

Savings in diverted solid waste disposal costs are dependent on whether the municipality in which the program is located operates its own facility or franchises out to contractors. In another secondary sense, the savings value varies with the cost of the disposal method.

Sanitary Landfill--

Benefits of source separation on landfill operations include a decrease in the rate of use of remaining landfill space and a decrease in landfill equipment use. Land costs are assumed to represent $0.50 of the total disposal cost per ton based on 10,000 tons per acre and a net land cost of $5,000/acre. Therefore, diversion of recyclables can be assumed to potentially save $0.50 per ton in land costs at the landfill (56).

Assume that a track dozer can spread and compact up to 80 tons of solid waste per hour, and that costs for equipment and labor average $40 per hour. Under these assumptions, the savings in operating costs amounts to about $0.50 per ton if wastes are diverted by source separation. Thus, a total diverted disposal cost savings of $1 per ton can be assigned to source separation when disposal is handled by a municipality. If disposal is contracted out, then savings can be as high as $4.00 per ton.

Incineration--

The diversion of materials from incineration through source separation activities can be expected to reduce equipment usage and residue disposal requirements. Further, there is a net benefit to energy efficiency when noncombustible recyclables are removed. Incineration costs range from $20 to $30/ton with an average of about $20/ton. A breakdown of incinerator operating costs with attendant diverted tonnage applicability is shown as Table 33 (56).

TABLE 33. INCINERATION COST ELEMENTS AS A PERCENTAGE OF TOTAL PLANT OPERATING COSTS

Operating cost element	Percent of total operating cost	Applicable to diverted tonnage
Operating less residue disposal	27	27
Maintenance and repair	22	22
Administration and supervision	8	0
Pension	4	0
Fuel and utilities	2	2
Amortization	20	0
Miscellaneous	17	0
	100	51

In addition, ash residue must be hauled for final landfill disposal. Residue transport costs vary with many factors, but can be assumed to average $0.50 per ton of residue (56). Total costs can be assumed to be equivalent to the costs in the preceding landfill discussion.

A 95 percent reduction of weight of material can be assumed for paper wastes. No such corresponding weight reduction can be assumed for glass and metals, both noncombustible, if processed through an incinerator. An average of $11 per ton can be assigned to source separation as a result.

TYPING GUIDE SHEET

SECTION 7

STATE-OF-THE-ART PLASTICS AND GLASS WASTES RECOVERY ABROAD

INTRODUCTION

The study of technologies for plastic and glass waste recovery and recycling in other countries has limited but worthwhile application to the United States. In most foreign countries, capital is scarce and labor usually plentiful. Therefore, emphasis is most often placed on labor intensive materials extraction rather than energy-capital intensive extraction techniques as used here in the United States. In the industrialized nations of Europe and Japan where the situation is analogous to the United States, maximizing human energy is becoming increasingly important as fossil fuel-derived energy costs soar. It is expected that this will also be true, if not already, for the United States.

In this study, both developed and developing nations were reviewed. The countries surveyed included:

- Australia
- Britian
- Canada
- Columbia
- Cuba
- Denmark
- Egypt
- France
- Holland
- India
- Israel
- Italy
- Japan
- Scotland
- Sweden
- Switzerland
- West Germany

In general, the state-of-the-art for plastic and glass recovery from municipal waste varies from industrialized to developing nations. In Europe and Japan, both labor- intensive and high technology applications coexist. In developing nations, low technology applications predominate.

OVERVIEW AND BACKGROUND

Materials and energy recovery from solid wastes has traditionally been practiced around the world and in the United States. In some countries, recycling practices have remained relatively static for thousands of years although materials have changed. Some countries are more advanced than others depending on the degree of technological sophistication and industrial-commercial organization. These rely more on state-of-the-art techniques.

In Cairo, Egypt waste materials have been recycled for thousands of years by so-called "refuse people" who live outside Cairo in their own

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"refuse city". Today they collect and process source separated wastes in much the same manner as in the past: oxen drawn carts are used for collection of refuse. Of course, smelting of aluminum, glass product production and plastic reclamation are relatively new (110).

In Japan, plastics reclamation from municipal waste is more widely practiced than elsewhere especially by technological methods. A significant reason behind this is that plastics represent a greater percentage of the Japanese waste stream, energy is at high premium, and recycling is highly institutionalized. In fact, Japan passed a law recently mandating nationwide recycling (111).

In Europe, there are found similarities with the United States in issues, objectives, and technologies. Europe is slightly more advanced in some areas, especially market development for secondary plastic products.

Since many countries in the world have had to exist in a resource or energy scarce framework, it behooves us to view activities around the world and to judge whether such methods, products, or approaches demand attention here in the United States, as we are now faced with a similar situation.

This section is organized into plastic and glass components. A case study approach is used to report on those technologies and methods considered representative. By no means is the treatment here considered comprehensive, but rather illustrative of state-of-the-art. In a few cases, documentation of why recycling does not exist is provided.

For the most part, details are lacking. Older programs were contacted, if possible, for update. Newer programs were not. Costs, where available, were added.

WASTE CHARACTERIZATION

Critical to the study of these waste management approaches in foreign countries is the waste composition and quantity. Table 34 illustrates waste compositions for selected urban wastes streams from 15 different countries (112-114, 26, 92). For each country, the quantity of the components, the socio-economic infrastructure, and the waste management objectives of that country dictate the resource recovery response.

In the developed nations, plastics and glass form a large component of the waste streams, while the developing nations, represented here by Cuba and Colombia, show very low percentages of such wastes. Even so, Europe and Japan place higher priority on energy recovery than material recovery. In developing countries, the emphasis is on labor utilization as energy is scarce. The smaller quantities easily support "landfill pickers," or materials reuse programs. It is important to note here that Cuba and India currently employ total container reuse programs.

PLASTICS WASTE RECOVERY

European Technologies

In Europe are major pilot scale research efforts which hold a promise of plastics recovery from municipal refuse. However, plastic specifications are not written for recovered materials, hence firms involved in primary manufacturing are reluctant to purchase recovered materials.

Mechanical Recovery--

The most successful of the high technology plants is the Flakt RRR System. RRR, which stands for "Resources Recovery from Refuse", consists of three basic units, the Front End, (primary shredder, trommel, screen, air classifier, magnetic belt separator, secondary shredder and secondary trommel); the Back End (flash dryer), and the Upgrading Unit (air classifier and trommel). After 3 years of testing by the Swedish Flakt Group, a commercial RRR plant has been constructed in Holland and is undergoing shakedown. Built for 84 million dollars with an annual capacity of 120,000 tons, the facility is recovering materials and a refuse-derived fuel. It is anticipated that another plant will be operational in Sweden during Spring 1980 (115).

According to Flakt, the system is self-sustainable at material recovery efficiencies of at least 30 percent and minimum selling price of $30/ton (for metal and paper). Costs per ton for processing and operation total $13 (115). It is important to note that plastics are considered a contaminant to paper and are not currently sold, although the mixed plastic fraction obtainable is relatively free of contaminants.

The following discussion is keyed to Figure 20. In a Flakt 3R System, the waste is first delivered to the receiving station and is then conveyed to the shredder (1) for coarse shredding. It then passes through the trommel (drum) screen (2) to the air classifier (3).

From the air classifier, the heavy fractions fall onto the conveyor (6) and the light fractions are moved by the air to the cyclone (4). Most of the air to the cyclone is recirculated by means of a fan. The exhaust air is passed through the filter (5).

The heavy substances, falling though the air classifier (3), are delivered to the magnetic separator (7) which retains the ferrous content. This consists predominantly of light cans and the minor portion of solid ferrous items.

The light waste entering the cyclone consists mainly of paper and plastic sheets. It is transported to the shredder (8) for fine shredding. After fine shredding, it passes a secondary trommel screen (10) where a fine organic residue is separated (11).

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TABLE 34. WASTE COMPOSITION IN VARIOUS NATIONS

COMPONENT	LOCATION[a]															
	Holland	Sweden	Stockholm	Stevenge U.K.	Rome	Hamburg	Vienna	Prague	Sofia	Tokyo	Madrid	United States	Australia	Havana, Cuba	Medellin, Colombia South America	United Kingdom
Paper	22.6	40-50	45	33	18	34.8	35.3	13.4	10.0	41.0	15-30	32.8	39.3	30	22	43
Iron and Steel	3.2	4-8	6	7	3	4.2	9.7	6.2	1.7	4.1	2.5-6.0	8.2	23.3	3	1	9
Mixed Nonferrous Metals	0.4		0.5	<1								1.0		<1		
Glass	11.9	8-10	7	10	4	15	9.1	6.6	1.6	7.1	2.0-10.0	9.8		<1	2	9
Plastics	5.3	4-8	9	4	4	4.5	5.5	4.2	1.7	8.4	3.0-12.0	3.7	3.3	<1	5	5
Textiles and Rubber	2.6	2-6		4		6.1	5.6	8.1	7.0	3.9	1.3-12.0	4.1	3.9	3	4	--
Food Wastes (Garbage)	48.2	8-20	17	14	50	16.7	24.1	41.8	54.0	24.4	30.0-60.0	16.6	23.3	25	56	23
Other Organic Materials			8.5			-	-	-	-	4.5	0.2-5.0	22.2	3.7	25		
Sand, Stones, Other	1.4		7	28		18.7	9.9	19.7	24.0	6.6	2.0-6.0	1.4	3.2	5	10	10
Inorganic Materials	-	-	-	-	-	-	-	-	-	-	-	-	-	5		2

In some instances, the columns do not total 100%. Not every component of the waste was always classified.

[a] Following references were used:

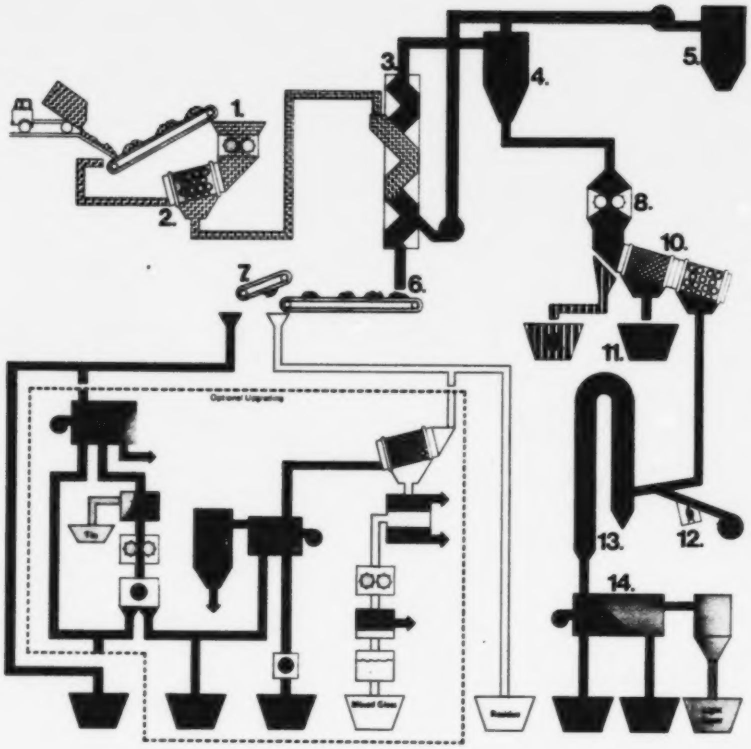

Figure 20. Flow chart for Flakt 3R system

The part of the plant after the second trommel is used for drying, sterilizing and finally separating paper from plastics. The plastics content is "shrunk" by the heat supplied in the dryer (13), and can then be separated from the paper in the air classifier (14).

Another mechanical process that is operational is the Sorain-Cecchini System in Rome, Italy. Rome, a city of 2,000,000 population, generates an average 800 g of household waste per day per inhabitant for a daily total of 2,000 Mg (116). In the mechanical sorting system, two plants (600 Mg/day and 1200 Mg/day) work in two shifts, six days per week. Waste incinerators are run continuously. Collection of waste by noncrushing compactors occurs daily with recycled plastic bags used for refuse storage by residents. It is noted that prior to introduction of the recycling system, waste was disposed by dumping and subsequent processing by Roman gardeners for pig feed and compost.

The systems recover paper, iron, plastics, animal feed, compost, steam, glass, and electric power. The system has been operational in one form or another for 15 years. Inerts, wood, rags, leather, and materials escaping processing for recovery are incinerated. This amounts normally to 35 percent of the total waste processed. Combustion of this fraction produces steam of 8 ATM. saturation which is used for internal purposes (animal feed, sterilization, etc.) and for sale to a neighboring industrial plant (116). Ashes amount to 33 percent of the incinerated portion. This is currently landfilled.

Plastics are recovered. Three markets exist:

- Sovain - Cecchini's plastic manufacturing division
- Sintac - a plastic molding plant
- F.A.P. - a plastic molding plant

Part of the plastic recovered is regenerated by Sovain-Cecchini and used to make polyethylene sacks for waste collection. Its commercial value amounts to about 70 percent of that of virgin polymer (116).

Since most plastic in Rome is polyethylene, there is less of a problem with incompatibility of blends. Reclaimed plastic is sent from the system to intermediate processors, who granulate the polyethylene (116).

The mechanical sorting facilities are little influenced by separate collection. According to the sources used, Rome has also a compatible secondary materials collection system (source separation) which reduces paper proportions to less than 18 percent of the waste stream.(116)

There have been several pilot and experimental systems developed by other research groups and government entities throughout Europe. These are not individually reported here as they do not recover plastics. It is important to note that the energy value of plastics enhances combustion in incineration systems which are common throughout Europe. These experimental processes noted above attempt to improve combustion characteristics or at least concentrate fractions for better fuel quality.

Source separation--

The best example of plastics reclamation via source separation is that conducted in France (117). The cities of Lyons and LeHavre both recover PVC from municipal waste. In a joint effort, the Ministry of Commerce and Small Businesses and the plastics industry have drawn up a program to purchase PVC recovered from mineral water bottles, wine bottles, oil containers and vinegar containers (117). The glass and plastics industry in these two towns are cooperating to collect mixed lots of plastics and glass which is separated later by mechanical means (117).

The recovery of PVC is conducted by a regeneration plant that was built just to accept PVC. Annual capacity of the source separation system is about 3700 Mg. PVC must contain less than 5 percent of impurities and less than 3 percent of polyethylene (117). The means of collection is by separate truck, door-to-door service and by use of 3.3 m^3 containers sited at convenient locations (117).

The firm of Mono Containers, Ruislip, Great Britain which has about one-third of the British polystyrene cup market, is assessing the economics of collecting, washing and recycling discarded cups (118). The firm's recycling service is still at an early stage, but the company reports it can offer regranulated polystyrene for industrial use in packaging materials.

Canadian Plastics Recovery

In Canada, Tonolli of North America reclaims battery casings and internals composed of polypropylene (119). Batteries are initially emptied by hand (dumped into a holding pond for acids) and cracked by sledgehammer. Tossed onto a conveyor belt, the batteries are reduced in size by a crusher to 58-80 mm (2-3 in) particles. These are then conveyed to a sink-float mechanism where metals and plastics are extracted. Plastic is conveyed to a waiting semi-trailer.

Australian Plastic Waste Recovery

According to the literature, Rolls-Royce (Composit Materials) Ltd. and Nylex Corporation Ltd. formed a joint company, Bristol Composite Materials Ltd., to employ a process for reusing plastics and other materials (120). The process separates and recovers each of the components in waste material so that they can be turned into end-products with markets of their own. It has already been applied successfully to PVC insulated cable and coated fabrics in pilot operations at the Nylex manufacturing plant at Mentone, Melbourne, Australia.

Also in Australia, a plan to recycle scrap plastics into usable products was announced by ICI Australia (121). The company bought the Australian license for a British process which is capable of recycling all plastics, including those incorporating foreign matter.

Developed by Plastic Recycling Ltd., the recycling system was sponsored by the British Government's National Research and Development Corporation. Unlike certain other recycling systems, the process can accept a wide range of mixed plastic waste including that containing such materials as glass or metal. It is expected that initial recycling will be of scrap plastics drawn from industry.

Egyptian Plastic Waste Recycling

Plastics waste recovery in Egypt is enhanced for a simple reason. Only two or so types of plastic are distributed, making reclamation technically and economically feasible. A family industry exists for labor-intensive collection and cleansing activities for the plastic wastes. Outside Cairo, waste is transported by collectors using carts to an area where separation occurs. Plastics are cut and cleansed with knives and caustic solution, respectively. Over 901 kg (1 ton) is processed daily. Material is stored in the open in piles. Later, it is deposited in a vehicle supplied by a plastics manufacturer.

Japanese Plastic Waste Recovery

In Japan, disposal of plastics wastes is considered a government problem as well as a responsibility of its industries. Accordingly, there is great activity in the technology of plastics recovery.

A significant reason for this activity and a force behind the recognition of waste as a problem is that Japan's per capita waste generation is surpassed only by the United States, and land for disposal and use is markedly more limited.

As a result, several techniques ranging from technological to labor-intensive have been developed. Using primarily clean feedstocks, plastics have been experimentally pyrolysized, co-extruded into secondary products, or reclaimed as scrap for substitution products via source separation.

In Funabashi, Japan, plastics are collected in small polyethylene sacks which are easy to handle (122). This material is sold directly to industrial process with little or no cleansing.

Also at Funabashi there is a plant where relatively "pure" plastics are crushed and washed. Using a process similar to one employed by the United States Bureau of Mines, materials are conveyed to a primary shredder and the resultant material is air classified to heavy and light fractions. Figure 21 shows the operational flow diagram (122).

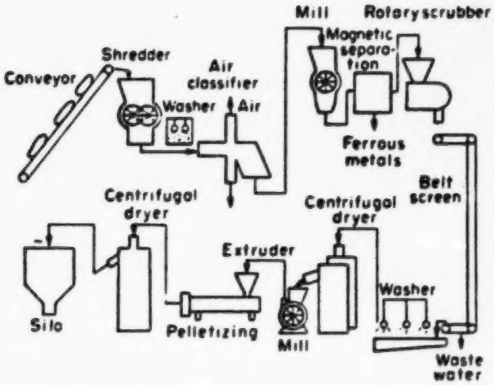

Figure 21. Flow sheet of separation of garbage (Funabashi, Japan)

After classification, plastics are milled, magnetically separated for "light" ferrous and washed.

The particles are then dried in a hydroextractor, pulverized, extruded and granulated. These granules are processed as usual by an extrusion press or by injection molding machines.

It is evident that this is acceptable as a method of reuse only when there is a market for products with a poor shock-and-tear-resistance. At Funabashi the plastic waste of about 150,000 inhabitants is reprocessed to commodities like flower pots and fishbaskets.

The Reverzer machine of Mitsubishi Petrochemical, Tokyo, Japan, reportedly can rework mixtures of plastics in molding film or fiber form (122). Depending on the final end use, the machine can accept up to 50 percent nonplastic material including glass, paper, and cloth.

Currently (1978) 20 Reverzer units are operating and producing molded items such as fence posts, rails, cable spools, 2 x 2 and 2 x 4 lumber replacement, and large u-shaped gutters (122). Costs for the fence posts were $.35 Kg ($.16/lb). Each system costs about $130,000 and consists of:

- a rotary shearing mill
- the reverzer (like an extruder)
- a 155 mm (6.25 in) accumulator/screw-injection cyclinder
- conveyor mold mounts
- shower cooling station

Throughput is rated at between 295 and 500 kg/hr (650 and 1,100 lb/hr) depending on the mix.

Figure 22 shows a cross-section of a plant using a Reverzer (122). Crushed plastic is mixed with an expanding agent and sometimes with a filler, such as sand. Passing the Reverzer, the material is compacted and heated, and subsequent cooling and hardening occurs in a mold.

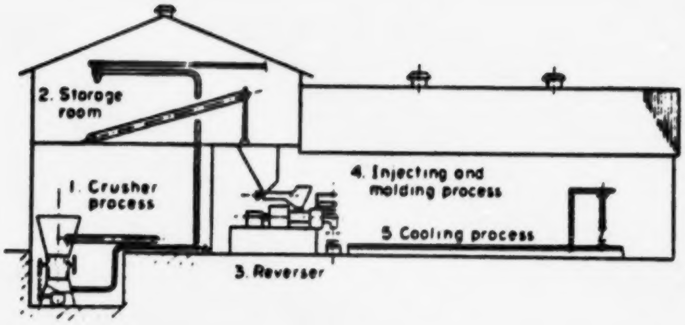

Figure 22. Plant for regeneration systems

The successful use of plastic waste as a material for producing wire and cable spools was reported in the literature (123). Spools are molded directly from the ground plastic waste obtained from the homes of the spool company's 100,000 employees through a company-sponsored buy-back collection program. On specific days employees bring segregated their plastic wastes to the company.

Experimental Processes

There were reported in numerous literature citations, various experimental methods for the processing of plastics such as pyrolysis, microwave treatment, flotation, and partial oxidation. These are not reported here as they are not commercially available, nor are they close to successful continuous use. A few of these processes are listed below (26):

Japan Steel Works Co.	Melting and pyrolysis of thermoplastic material in an extruder body.
Japan Gasoline Co.	Pyrolysis of dissolved or slurried plastics in a conventional tube furnace
Prof. Tsutsumi (Univ. of Osaka)	Pyrolysis of foam PS in a tubular reactor using superheated steam as heat carrier
Nichimen Co., Ltd.	Pyrolysis of noncharring polymers in a fixed catalytic bed
Toyo Engineering Corporation	Pyrolysis of noncharring polymers in a fluidized bed
Mitsui Engineering and Shipbuilding	Melted low mol. wt. PE and APP pyrolysis in a stirred tank reactor at 400-500° C
Mitsubishi Heavy Industries	Melted plastics are pyrolyzed in two steps: PVC decomposition at 300° C, followed by final decomposition at 400-500° C
Kawasaki Heavy Industries	Pyrolysis in a bath of molten PE and PS
Japan Gasoline Co.	Stirred fluidized bed for pyrolysis of shredded PS
Sumitomo Shipbuilding & Machinery Co.	Partial oxidation of plastic waste in a fluidized sand bed
Prof. K. Yoshida (Univ. of Tokyo)	Partial oxidation of PS chips in a fluidized sand bed

Summary

In summary, the technology for recovering prompt scrap has been established and producers will generally reuse production by-products unless they are the result of some mixing process (e.g., mixed with other plastics).

State-of-the-art for pyrolysis of plastics is regarded by many in the industry as doubtful. It has yet to be demonstrated that the energy obtainable from pyrolysis of plastics into "oils" is greater than the energy put into the pyrolysis operation.

The technologies currently in successful operation utilize labor intensive source separation and mechanical approaches which maximize human energy.

MARKETS FOR RECOVERED PLASTICS

Most plastic recycling involves industrial reuse of in-house waste material. On the municipal level, the markets are limited.

The Swiss plastic waste recycling company, Rehsif SA, is the sole producer of the Reverzer machine and the newly introduced "klobbie" (28). The principle behind this recycling process lies in the use of mixed thermoplastics. This is different in concept, technology and economics from the conventional procedure of using a single-polymer scrap (28).

The waste sources for the two machines are:

- Waste from plastics processing industries
  - composite fiber scrap
  - laminates
  - coextruded fiber and scrap sheet
  - coextruded bottle scrap
  - printed film scrap
  - assemblies containing more than one polymer
  - contaminated injection and extrusion machine purgings

- Waste from metal recovery processes
  - battery cases
  - cable strippings

With materials that may contain 3 or 4 different "thermoplastics," the recycler must, find a blend that optimizes acceptable product quantities. A key in the processing, then, becomes homogenizing the blend to a limited extent. This can be accomplished by devising special equipment (extruders) with special characteristics (28):

- high rate of shear
- high turbulent flow
- high temperature
- very short residence time (to reduce decomposition caused by the other characteristics)

Traditional compounding operations waste energy by cooling the product, usually a granulate, which is then heated during subsequent processing in an extruder or injection molder. In mixed plastics recycling the hot material coming from the compounding unit is directly processed into finished product. This is accomplished by:

- flow molding (material is directly inserted into a mold) to form fencing, rails, cross ties, etc.

- extrusion (drain pipes)

- compression molding (cable drums and pallets)

Total costs, excluding capital costs for the machine itself is estimated to be about $.10/lb or $20/ton produced (28).

Scrap foam material is being used in West Germany to improve drainage of poor soils and also to aid moisture retention (122). The foams involved are urea-aldehyde and polystyrene. Forms are used to open up poorly drained soils and as a filter material around drainage pipes. Polystyrene material, trade name STYROMULL, is obtained by shredding scrap polystyrene foam. The material is mixed with the soil for landscaping and gardening. In agriculture, it is generally used in slip drainage to carry excess water through impermeable soil layers, and is trade named HYGROMULL. It absorbs 50 to 70 percent of its own volume in water, thus providing a continuous source for plant development. An additional benefit is that the material decomposes at a rate of about 5 percent per year in soils with neutral pH to provide plant food. Open pore foams are generally applied by mixing chopped material with soil.

Niigata Iron Works Company, Japan, developed a process for melt-solidifying plastics waste for reuse (120). Special melt mixing equipment was designed for mixing sludge into plastic waste. The plastic waste is crushed, ground cut-to size and mixed with dried sludge. The mixture is melt-milled and molded by a conventional plastic molding machine. Farm use and public work-use structural materials are molded from the plastic waste/sludge compound.

Hiroshima Kasei Company, Japan, is producing plastic carpets by mixing waste plastic into virgin material (122). PVC sheeting made of waste and virgin resin is used as the backing of the carpet. The surface is made of nylon by applying the Devlon process introduced by the Unitica Company of England.

In summary, the major application for secondary plastic products is as a substitute for concrete or wood. At present, the production cost of a simple item like a recycled plastic fence post is about the same as the selling price of a wooden post. Since the plastic post is rot-, insect- and animal-proof, it can be sold at a slightly higher price than the wooden one. However, the present profit margin is small. As the price of wood increases, this margin may become more substantial (120).

For a more complex item like a pallet, the production cost with recycled plastic is well below the production cost with wood and the economics of secondary recycling are improved (120). The plastic product is superior in that it does not require the high maintenance costs involved with using wooden pallets.

GLASS WASTE RECOVERY

As opposed to the very limited plastic recovery from municipal waste, there are numerous, although limited, programs glass recovery.

European Glass Waste Recovery

In Europe, source separate collection of glass has proved to be highly successful. The glass container industry in the United Kingdom is embarking on a sizeable capital investment to extend its "bottle bank" recycling concept on a national basis.

Bottle Bank System--

The United Kingdom (including Scotland and England), Switzerland, Germany, and France have glass container reclamation systems which invite householders to deposit source separated glass in specially marked 10 m^3 (350 ft^3) hoppers or bins.

In the United Kingdom, there are 32 such centers, but the proposed capital investment would extend operations to over 20 million people in 200 urban areas by the end of 1981 (124).

In the bottle bank system, clients (consumers and commercial establishments) take recyclable glass to designated bins (10 m^3) located at convenient spots, usually in easily accessible locations such as shopping centers. The bin is divided into 3 compartments for amber, green and flint glass. Holes are available (15 cm or 5.9 in) to allow passage of the bottles. Cooperation is voluntary and encouraged by extensive media promotions. Pilot operations are achieving at least breakeven level. An intermediary processing plant is an integral aspect of this method. The process includes collection of these bins by a broker, treatment at a cullet treatment plant, and subsequent reuse. Figure 23 presents a generalized flow diagram of the operation (124).

Both Rockwave Glass and United Glass of the United Kingdom Glass Manufacture's Federation have announced their intention to build a 45,400 Mg (50,000 ton) per year glass recycling plant to provide cullet for glass factories (125).

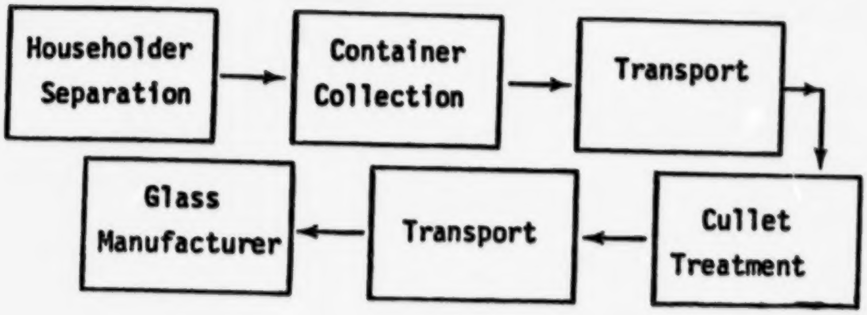

Figure 23. Bottle bank system flow diagram

In the bottle bank program, local authorities make a modest investment to provide collection containers and transportation. In return, municipalities are paid approximately 30 dollars per ton for flint.

In Switzerland, this type of recycling has been quite successful and over 35 percent of waste glass generated in the country is recycled (125).

Other European Source Separation Systems--

In the towns of Lyons, Bordeaux, and LeHavre, France, separate collection of waste glass is practiced. Glass (along with PVC) is collected door-to-door by separate trucks in mixed fashion and in 3.3 m^3 containers located at convenient sites. Door-to-door collection occurs weekly and fixed site containers are emptied weekly. The program itself is organized by the industry-community recycling program which resembles the U.S. BIRP. The purchaser of this glass is CYCLA FRANCE CO. which sorts glass from PVC. Impurity content of the glass must be less than 5 percent. The purchaser is a typical intermediate cullet processor, with a type of operation similar to those in the U.S. (117).

There is also an established bottle reuse program in France. In almost all cases, standardized, mass-produced bottles for vintage wines were collected by bottlers, cafes, garbage collectors, street cleaners and other salvagers. In 1978, over 1,000,000 bottles were returned (117).

The Swedes currently operate a system of source separation. Householders segregate cans and bottles, newspaper and other waste. The two containers for cans and bottles, and the newspaper are placed at curbside for weekly collection by specially designed trucks. A central facility separates the cans from the bottles. Steel is magnetically removed. The glass/aluminum fraction is crushed, and screened at 19.6 mm (1/2 in); over-sized is segregated for aluminum. Cullet is transported to a glass plant (126).

The Redfearn National Glass Company, in the City of York, England, conducted a test source separation program only for glass (124). During 1976 the company, in conjunction with York, tested 100 households for curbside collection of the material.

Two large paper sacks, one for clear glass and one for colored glass were delivered to each household, and the publicity program advised the householders to remove metal and plastic caps and lids, to separate glass by color in the two paper sacks and to avoid disposing of returnable bottles, old window glass, mirrors, bulbs, etc.

Twice a month a collection truck would collect the bags. An analysis and research exercise was undertaken together with a check on the efficiency of separation, cleanliness, the amount of nonreturnable containers and the number of contaminants such as lids and caps. Initial reaction ranged from "good" to "very enthusiastic."

The first collection was reportedly satisfactory, because people had stored bottles following the test program's advance publicity. They had also taken the opportunity to clear out cupboards, garages and sheds. Towards the end of the campaign there was a reduction in the quantity collected, but more noticeable was the decline in quality because closures had not been removed from containers and, in some instances, sacks contained waste matter other than glass. Returnable bottles, some of which carried deposits of five pence, made up a surprising percentage of the glass containers collected despite the request that these should be returned to the point of purchase.

The number of sacks returned during the program amounted to 50 percent of the sacks initially delivered. The cost for collection amounted to 70 dollars per ton while revenue was approximately 70 dollars per ton for flint and 10 dollars per ton for colored glass.

The most important conclusion drawn from this study was that it is too expensive to reclaim glass packaging in isolation from household waste. In other words, metals, paper, etc. must also be collected.

In Copenhagen, Denmark, households participate in source separation where paper is separated in one sack and glass/metal in another sack, and collected twice monthly (124). Approximately 15 to 20 percent of the domestic waste stream is reclaimed. Participation has ranged at about 70 to 90 percent; however, revenue is low because market conditions are unstable and unreliable.

The German glass industry has also initiated a collection program. Between 1974 and 1979, the program has collected over 1,290,000 Mg of glass (128). The rapid expansion of organized glass recycling is best described by a comparison of years 1974 and 1978.

	1974	1978
Counties and independent cities covered	16	274
Inhabitants in 1,000	3,045	41,812
Percent of total population	5	68
Area covered (km^2)	11,019	191,447
Percent of the area of the Federal Republic	4	77
Specialized firms active in glass recycling	7	80
Number of glass containers (skips)	200	15,000

The 1978 figure for recovery amounts to 13 percent of the glass container production and 2 percent of the total municipal waste load. The programs are not linked with municipal waste services (128). Rather, private waste disposal contractors handle collection of the fixed-location containers.

Processing of collected glass is conducted at any one of approximately 20 processing plants spread throughout Germany. Mostly they are sited near glass manufacturers. Currently the processing schemes used do not segregate according to color (128).

Dipl. -Ing. G.A. Classen has provided a history of glass cullet processing in Germany (129). Figure 24 presents a schematic representation of the processing of salvaged glass on a small scale involving high labor cost as it was about the year 1957. The capacity of such a working process was of the order of 6 - 8 tons per 8 hours.

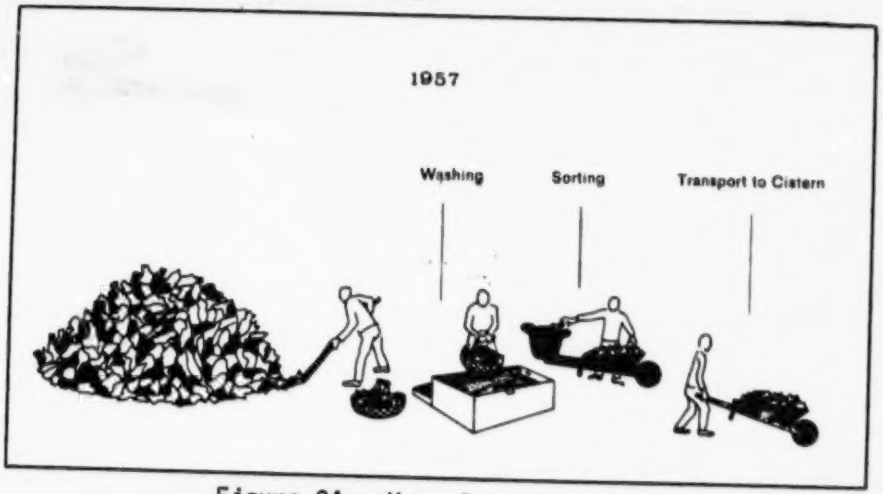

Figure 24. Manual processing

Figure 25 presents a processing plant about the year 1961, by which the conveyance and dressing operations were performed mechanically. The magnetizable metal pieces were separated from the glass by means of a magnetic separating drum provided that they did not stick together with the cullet of greater size. All other foreign bodies had to be sorted manually. The output of 30 - 60 tons per 8 hour shift using 8 workers depended on the degree of impurity of the cullet.

The subsequent Figures 26 and 27 present more advanced stages of development. Figure 28 shows the present state.

In Holland, glass recycling has been implemented using the familiar "skiips" in fixed locations with small bins. Over 600 such bins have been placed. The rate of individual participation per participating municipalities is shown in Table 35. Most municipalities fall in the range of 30 - 50 percent participation (130).

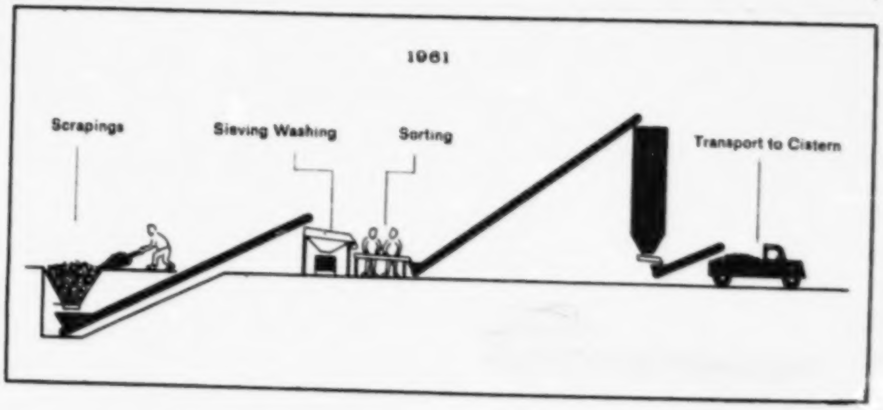

Figure 25. Origin of the efficient processing

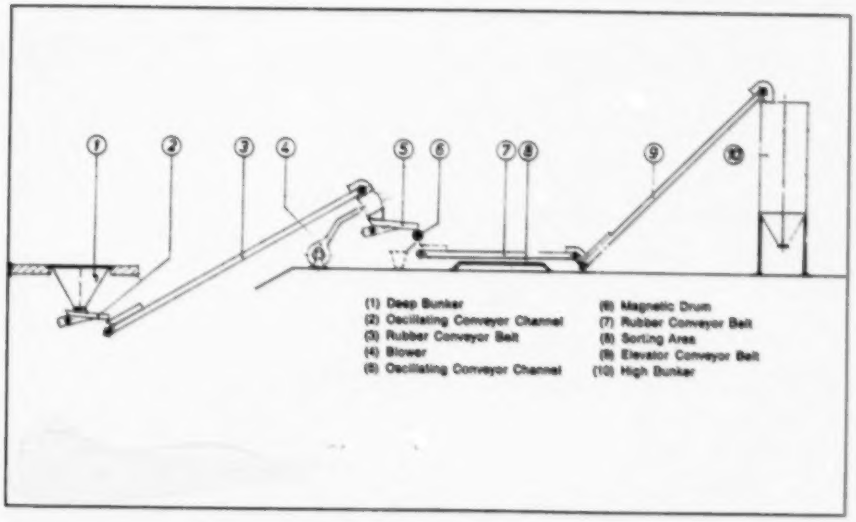

Figure 26. Added blasting device and magnetic drum

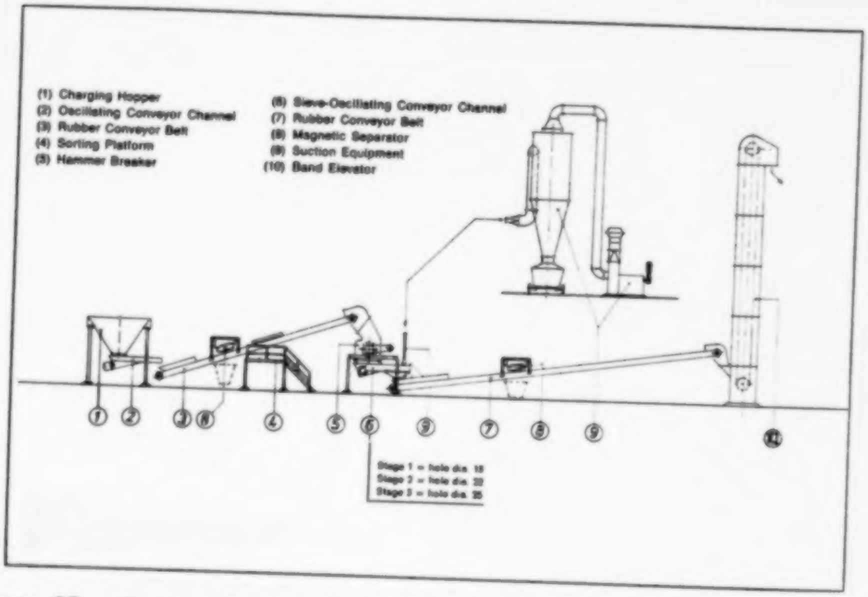

Figure 27. Processing with crusher, conveyor and air classifier

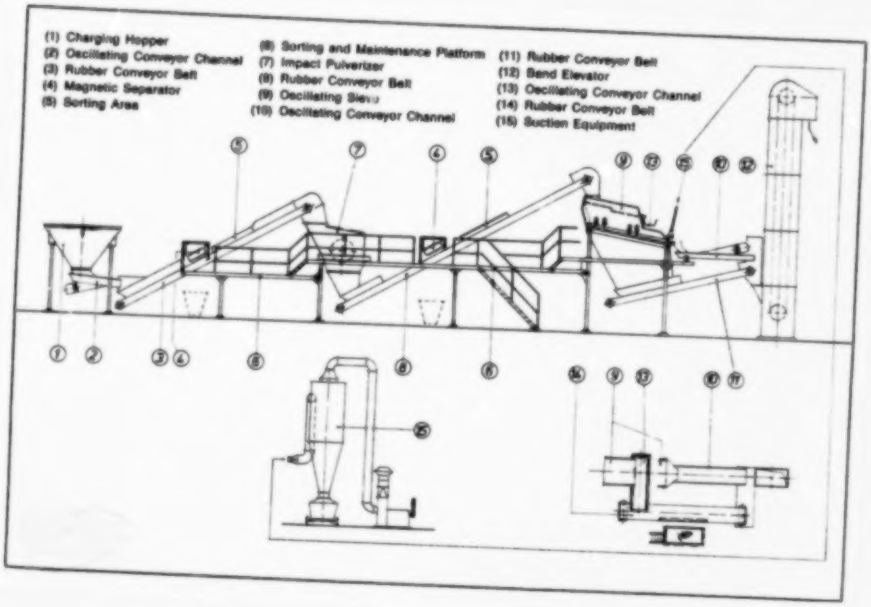

Figure 28. Present state

TABLE 35. RATE OF PARTICIPATION PER MUNICIPALITY

Participation rate	Number of municipalities	Percentage	
20	2	20	
20-25	5		
25-30	13		
30-35	19	27	49
35-39	8		
39-45	13	22	
45-50	3		
50	6		
TOTAL	69		

Other Countries and Programs

In other countries, source separation systems predominate.

Canada--

Most cities in Canada have citizen associations which operate nonprofit depots for collecting glass and paper (131). The operations usually collect materials for patrons using the drop-off center approach. Large bins or small containers are used, and material is transported to market by a broker.

A citizen-government program in Toronto is collecting newsprint and bottles using a newly designed multi-material truck. Newspapers are placed in the center of the rear lift, and bottles are placed in side compartments. The lift is drawn up and materials are scooped into the truck body for transfer. Doors at the back open for easy dumping (132). A unique feature of Canada's solid waste system is that metal beverage containers (especially aluminum) are banned (133).

Israel--

In Israel, bottle reuse is voluntary but widely practiced (134). The military handles the system and about 90 percent of the people participate. (A sidelight is that, in most cases, bottles are encased in a plastic sheath to retard explosion of the bottles). A deposit is placed on all containers, and the army places convenient containers for collection at retailers. The container return program depends on the following variables:

- Continued administration of the program by the Armed Forces.
- Continued convenient access to containers for deposition of returnables.

- Continued program promotion by the state.

- Apparent resource scarcity.

They use 6 m^3 (8 yd^3) containers which are spotted at convenient locations for use by Israelie citizens. This is considered a part of public services.

Colombia--

In Medellin, Colombia, South America, there are four distinct levels of recycling (113). Households and businesses accumulate recyclables for sale from the first level. At this level, the highest grades of paper, bottles, cans, boxes (corrugated) and textile are recovered. Materials are source separated and sold directly to brokers or their sole agents. Not all businesses and households recycle, however.

The second level of recycling are the 3,500 door-to-door buyers, who scavenge wastes generated at households and businesses. Materials are sorted, upgraded and delivered to market, normally by handcart.

The third level concerns the 420 solid waste collection workers who have access to marketable waste products. Crew members preselect materials enroute and sell these to purchasers prior to off-loading at the landfill.

The fourth level is comprised of basuriegos or trash pickers at the landfill site. Materials are normally mixed and highly contaminated at this level. The actual activity then occurs as follows:

> The trash is dumped at the landfill. Trash pickers sort out recyclables into containers. Trash pickers sell their products to a compradore or middle man at the landfill. Materials are then cleaned as necessary and sold to a intermediate processor in town. Normally 0.5 peso per bottle is spent by the middlemen. They resell bottles at 1 peso cash to processors (113).

It has been estimated that over 4,000 bottles are collected daily. Bottles are washed and reused. Glass fragments are generally unrecycled due to lack of markets for glass manufacture within a reasonable distance.

Cuba--

In Havana, Cuba, the emphasis is on preventative waste reduction (92). In keeping with this attitude of preventative action, solid waste is discouraged. A primary reason for this is that collection resources are few and scattered and the disposal network is managed by local agencies generally without national or regional direction. Fortunately, the government has kept the glass washing operations in order from pre-socialist days. As a result, the amount of glass in the waste stream as disposed is negligible. Recycling broken glass is usually the responsibility of the neighborhood block organization which also recycles paper. A car or truck will be designated periodically to take recycled glass back to a glass manufacturing plant. It was noted that glass washing operations are generally sited with glass manufacturing plants.

Egypt--

In Cairo, Egypt, refuse men use "tailer trains" of a nineteenth century concept, two wheeled carts pulled by shaggy donkeys (110). Trash collected from the households is loaded on the carts and hauled to a most unusual village in the nearby Mukattem Hills. After the daily pickups and the long ride back to the Refuse Town each day, the contents of the donkey carts are dumped on the ground around the family's hut, and the refuse is sorted. Rags, bottles, food, bones, paper, wood, metal and broken glass are left in separated mounds until the arrival of the middleman with a large wagon or sometimes a small truck. Bargaining begins, and when an acceptable price has been decided upon, the segregated items are taken away.

The middleman, in turn, sells his acquisitions to conversion plants, most of them very small, that recycle the wastes as they have been doing for innumerable years.

The glass is either reused or utilized in some manner. Recycling is conducted either at the recycling plant or at the "refuse city". Low grade melting can create a "vase" or an ash tray which can then be sold at the Cairo Central Market.

India--

In India, bottles are generally reused. Broken glass is normally collected for disposal. Whole bottles are redeemed and washed at glass bottling plants (135).

Japan--

In Japanese cities with populations of less than 300,000, source separation is widely practiced (136). Recovery conducted by handpicking, screen sorting, and magnetic separation represents mechanical applications. Very few cities practice mechanical recovery solely.

Incineration in Japan has increasingly relied on source separation for improving combustion. The most popular bin of recovery has been the "group recycling" or recycling center as it is known in the U.S.

In 1978 over 204 communities practiced extensive source separation. Normally, over 20 percent of the waste stream is recovered (136).

In Hiroshima, recyclables are gathered at curbside by categories of noncombustibles, bulk and recyclables.

In Numazu City there are no large-scale industries. Mostly marine and fishing products are made. Wastes are incinerated. In 1973, waste management and environmental controls were so bad that the citizens blockaded the landfill/incinerator. The trouble was resolved when the city and citizens set up a pollution agreement which emphasized recycling and proper controls on incineration. In the city once a month collection occurs for glass and metals. Using block associations over 500 open spaces were dedicated for a once-a-month collection site. Citizens may bring recyclables only on the day and the night before. Each neighborhood group has a recycling coordinator who transfers recyclables to the site. Refuse collectors and volunteers man the stations as needed. A portion of revenue is returned to the citizen groups (136).

Glass Processing and Recycling Abroad

The most important integral factor after collection considerations is marketing of recyclable materials. As in the United States, recycling of glass is wholly dependent on finding suitable market for recovered materials. For glass materials, the market has primarily been the glass manufacturers themselves who reuse glass cullet in new product manufactured (primary recycling) and in secondary recycling, where products are remade or reworked into lower quality uses.

In countries where recycling is being conducted via source separation, glass is indeed being remanufactured into new primary products. However, there does not currently exist a market for primary recycling utilizing those waste materials recovered from mechanical sorting processes. This underscores the first level of any effort to utilize waste glass. It must be segregated from other unwanted material. This was described earlier.

Secondary recycling has been somewhat more "open" to source separation and mechanical materials recovery. Use of glass material for construction aggregate has been attempted with limited success in Europe. A problem is that aggregate, basically used in road construction, has not had the resilience and durability of pure concrete or asphalt roads. In the United States, the impact of heavier road traffic, both in individual vehicle volume and number of vehicles, tends to limit this market application (137).

A German process, developed by Imperial Krauss, reduces glasses to near "powder". This, in combination with organic materials, results in an acceptable compost material. This process of grinding broken glass to a fine powder for use in a compost mulch has also been proposed for glass contaminated compost in Medellin, Colombia (113). In the past, unground glass fragments were incorporated into top soil along with organic residues (as a compost); but safety factors caused proponents to abandon this effort (113).

The construction of building blocks, e.g., Terrazo, has also been proposed in Europe; however, it is still unable to compete economically with less costly sand and silica (138).

In Cairo, Egypt, materials are reworked many times or remade into lower quality uses such as ash trays, containers, plant pots, etc. According to a world bank study still in draft preparation, the "refuse people" of Cairo both color separate their material for recycling and also prepared certain choice pieces for reuse. For example, bottoms of broken bottles are "fired" along jagged edges to reduce sharpness. The "molded" ash tray that results is usable and is subsequently sold in the central market (110).

The best literature source encountered on the subject of glass reuse was Breakspere, et al, the University College, Wales, United Kingdom (114). In this study, waste glass was used as a filler for cements and resins to manufacture floor and wall tiles, industrial castings, and sanitary fittings. Mechanical and physical properties of the product developed were discussed.

Essentially, new products were produced by filling resin or concrete with crushed glass.

In the laboratory analyses, bottles were color sorted, crushed with metallic rings and labels affixed and were unwashed. Castings in the forms of "flanges" were made which were without the usual cracking and deformation caused when polymerizing the two materials, resin and glass.

Finally, decorative panels were fabricated using colored crushed glass set in a resin contained in a shallow mold. Using a "sandwich" mold, two panels with an interior "foam" of about 3 inches can be used as a strong walling that has high insulation value.

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SECTION 8

RESEARCH ON PLASTICS AND GLASS WASTE RECOVERY/REUSE

INTRODUCTION

This section identifies selected research activities that have been or are currently being conducted on plastics and glass wastes which could enhance resource recovery. Research activities in countries outside the United States have been addressed in Section 7.

Some of the material discussed in this section has already been presented in prior sections. This material is again addressed so as to place research activities in perspective.

PLASTIC RESEARCH

Basic plastic waste recovery research programs generally focus on the site specific needs of manufacturers. These include: (1) processes for the chemical or mechanical separation of various blends of plastic waste, (2) processes or additives which improve the bonding characteristics of mixed plastic types, (3) development of specifications to both aid consumers in identifying plastics and to enhance recyclability and, (4) processes and systems to upgrade segregated plastic scrap types normally uniformly contaminated (e.g., PVC molded around copper wire).

Less research has been devoted to recycling plastics from mixed municipal refuse due to many factors, including cost-effectiveness, lack of markets, low volume, and lack of demonstrated need. In the United States, the research efforts focusing on municipal refuse as a source of plastic for recovery are combustion-energy recovery operations, which favor the high Btu content (42 kJ/g (19,000 Btu/lb)) of plastics, selected solvent separation, cryogenics, source separation, air separation, electro- dynamics, sink flotation, and research related to PET bottles.

Mechanical Processing

One such program of mixed plastic waste recovery is at Carnegie-Mellon University. Researchers are attempting solvent separation of mixed plastics (139). Previous work at this institute has resulted in a process by which mixtures of polyvinyl chloride, polystyrene, and the generic class of polyolefins can be separated. The solvents used consist of mixtures of xylene and cyclohexanone. The polyolefin fractions are compatible and separate out as a single fraction. Additionally, fractional crystallization is being investigated to separate polypropylene from various density polyethylenes in the isolated polyolefin fraction.

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Solvent separation needs a supply of essentially plastic material. Consequently, if this system were to be used for plastics from municipal waste, it would be used as a second stage, following a general process of plastics aggregation-segregation from the mixed refuse.

Case Western Reserve University is investigating the separation of plastics used in composite materials such as polyvinyl chloride coated fabrics and various laminates (139). The plastic composites are cryogenically ground, followed by flotation separation of the ground plastics. Cryogenic grinding is necessary since the majority of plastics used in composites are not rigid and can not be ground by conventional grinding methods. Cryogenics greatly increase the rigidity of the plastic material so that it can be effectively ground.

Another example is the combined research effort of the Bureau of Mines and Ford Motor Company to investigate the recovery of polyurethane foam and other assorted plastics from automobile shredders. In this analysis, all the foam and between 50 and 70 percent of the assorted plastics were recovered from two shredded 1972 automobiles via a combination of screening, water classification, and gravity separation (140). The composition of the reclaimed foam concentrates ranged from 46 to 66 percent foam. These were hydrolyzed in laboratory tests to produce a reusable liquid mixture of polyether glycol monomers and toluene diamine.

Three possible applications for plastic waste mechanical recovery are electrodynamic, sink flotation, and air classification segregation techniques. Electrodynamic techniques involve the separation of plastics from paper, sink flotation separates one type of plastic from another, and air classification separates heavy from light materials in municipal refuse.

The Bureau of Mines has focused efforts on developing mechanical methods for separating unburned urban refuse into recyclable fractions. One important phase of the plastic segregation research has been in producing a paper-free plastic concentrate as well as a plastic-free paper from unburned urban refuse. The use of a high-tension electrodynamic separator has the potential of being an efficient technique to separate plastics from paper.

Separation of plastics from paper begins with the feeding of the material to the electrodynamic separator by vibratory feeders. The material falls onto a rotating drum and is transported into the corona formed between an electrode and the grounded drum. The paper is drawn toward the electrode while the plastics adhere to the drum. As the drum rotates, the plastics are brushed free at the bottom.

Research tests have been conducted on this system by the Bureau of Mines. The following are conclusions drawn from these tests (141):

1. Recoveries of up to 99.4 percent plastics can be obtained.
2. Moisture content of the refuse has a pronounced effect on separation efficiency. Data have shown that moisture content above 50 percent yielded 100 percent pure product.

3. Research will now focus on incorporating this system into a continuous pilot operation, and separating the plastics into major classes (i.e., polyethylene, polystyrene, polypropylene, Teflon, nylon, and polyvinyl chloride).

Sink flotation is a process by which different types of plastics are separated by applying gravity methods in aqueous solutions. Experimental separations of the five major types of plastics (i.e., polypropylene, low density polyethylene, high density polyethylene, polystyrene, and polyvinylchloride) were conducted in an unagitated vessel with distilled water, a calcium chloride solution, and two alcohol-water combinations (142). A separation using only water as a medium was devised for separating waste plastics into three fractions, polyolefins, polystyrene, and polyvinyl chloride.

Hydraulic separation used for plastic segregation has been promising. In this process, the mixed plastics are fed into a sink-float separator that floats off polyolefins; the other two components, after they sink, are transported by airlift to an elutriation column. The polystyrene is retrieved from the overflow in the column and the polyvinyl chloride sinks and is carried by a second airlift to a receptacle (142).

Air classification is a process by which plastics material contained in organic fraction can be removed from municipal solid waste. The objective of air classification is to separate mixed materials by one or more physical properties including size, shape and aerodynamic characteristics. In the air classifiers, the light materials are carried upward in an air current while the heavier matter falls. Complications in the segregation of materials arise when (1) the type of separation desired crosses over the basic light/heavy distinction; and (2) there is a lack of uniformity in the aerodynamic characteristics of specific materials because of variations in size, shape, and density.

There are four different designs of air classifiers now being used to process refuse for resource recovery (143): (1) vertical, (2) horizontal, (3) rotary drum, and (4) air knife. Of the four designs, the air knife classifier is the only apparatus not used in an application of plastic material recovery.

Research is underway at two institutions to improve the mechanical properties of plastic blends since it may not always be possible to economically separate plastic mixtures into their respective components. Agents which would make them more compatible are of interest.

At the University of Texas, research has involved using a blend of polystyrene and low density polyethylene, which has very poor mechanical properties (139). When the blend included a so- called graft copolymer, mechanical properties were improved.

A different approach for improving the compatibility of mixed plastics is being investigated at the Polytechnic Institute of New York (139). They are looking at materials with a high potential for hydrogen bonding which could, in effect, serve as an agent to improve compatibility. This secondary hydrogen bonding force could be exerted between components of the mixtures, thus serving as an internal adhesive. Their initial work indicated that a blend of polystyrene and polyethylene oxide, which has very low compatibility and hence poor mechanical strength, shows a considerable improvement in compatibility when a synthetic agent was mixed with the blend.

At the University of Southern California (140), a cable stripping waste has been tested for conversion into speciality-grade transformer oil through a slow heat-soaking process.

PET Recycling

Researchers have offered a novel concept of recycling thermoplastic polyester polymers from reclaimed PET beverage bottles into raw materials for use in manufacturing unsaturated polyester resins. It was shown by Eastman Industrial Chemical Laboratories (144) that PET recovered from beverage bottles can be a valuable raw material for the synthesis of thermosetting unsaturated polyester resins for use in reinforced plastics. Reclaimed PET could significantly supplement the availability of other petroleum based raw materials currently used by the reinforced plastics industry.

Prominent results of the PET research include:

- Requires significantly less processing time than virgin resins
- Has viscosity values comparable to virgin resins
- Has physical properties which compared favorably with virgin resins.

Energy Recovery

Research has involved the recovery of energy from solid waste. Specifically, plastics are of interest due to their high energy content of up to 42 kJ/g (19,000 Btu/lb). The Btu content of solid waste as a whole averages about 12.0 kJ/g (4,500 Btu/lb) and rises with increasing fractions of paper and plastics in the solid waste. Research in this area has concentrated on finding efficient and environmentally clean methods of utilizing energy from waste. This aspect of waste recovery has been previously discussed in Section 4.

Source Separation

Finally, source separation offers methods of dealing with plastic wastes as disclosed in Section 4. Most efforts have been small scale.

One such effort was conducted at California State University at Long Beach (145). The State University's Recycling Program collected polyethylene (high density) milk jugs, washed them and gave them to the University's Plastic Technology Department (PTC). Researchers ground the material into flakes and extruded them into long cords of plastic. These were later heat injection molded into map-tack heads.

Container Deposits

An area requiring more research is the impact of container deposit systems on plastics recovery. A distinct problem is the inability of recyclers to obtain clean segregated scrap from post-consumer waste. In Michigan, a bottle deposit has been placed on 32 oz PET bottles. These bottles have been returned and thus form a segregated stream that can be reused.

GLASS RESEARCH

Research efforts for recovery/reuse have been concerned with mechanical separation, source separation, new secondary products and reuse programs.

Mechanical Separation

Mechanical separation research, based on proven mining and food products industry techology, has evolved several technical approaches that have had limited effectiveness in segregating glass waste from mixed municipal waste streams. Operating usually in combination with other processing systems, as described in Section 5, these approaches have included separation techniques, most often based on density and color differences. Froth flotation and optical sorting, and jig separation are most often named as effective in test situations. The major problem that has denied success is the degree of difficulty in rendering a usable product able to meet general market specifications within a range of cost-effectiveness. As previously discussed, the glass manufacturer must know accurately what ceramics, stones and chemicals are present and what has to be added in order to compensate for impurities and color distortion. These unknowns have detered manufacturers from using cullet purchased from mechanical separation schemes.

For the above reasons, research has been directed toward use of recovered glass in secondary products. They include highway surfacing materials, such as glasphalt, road reflectants, slurry seal; and building materials, such as bricks, construction panels, insulation, and terrazzo flooring. These uses are of particular interest in view of the quality and quantity of waste glass capable of recovery from municipal waste streams. However, a marketing potential and overall economic feasibility must exist for such secondary products to realize their full potential.

Source Separation

Source separation programs have been severely limited by requiring householders to segregate their glass into flint, amber, green or a combination of amber and green. Glass manufacturers and bottlers for quality control reasons have insisted on stringent color specifications as well as quality specifications.

In selected areas of the country, primarily California, mixed glass cullet markets do exist, and these buyers have greatly aided glass recycling. However, the mixed glass cullet market is limited at present to wine bottles and specialty glass production (146). The mixed cullet area of market development is undoubtedly a prime one for further research and demonstration.

One glass processor who is involved in source separation has proposed to develop a color segregator system. Recycling Enterprises, Inc. (REI) currently purchases segregated cullet but wishes to develop a system by which mixed cullet could be purchased from sources and then segregated at an intermediate operation (146).

Currently, REI separates ceramics and other contaminants by hand, a very expensive and slow process. There are commercial systems which can partially segregate but only at 1 ton per hour, too slow when compared with the current throughput.

The emphasis of the proposed system is to determine glass color on as large an object size as possible. To this end, after metal separation, the remaining articles will go through a screen sizer which sorts into bottles, half bottles, quarter bottles, and smaller. Each of the first three categories will be fed into individual color sorting heads capable of sorting green, amber, flint and miscellaneous. The greatest speed and volume will be achieved by the whole- bottle operation. Mechanical considerations dictate a smaller throughput for half and quarter bottles.

Each color sorting head will determine the color via transmitted light falling onto several narrow wavelength sensors. This information will be transmitted to either a single microcomputer for each head, or one microcomputer for several heads for determination, by mathematical processes, of the color. Since almost every type of bottle made has some degree of transparency, any object which is opaque is rejected. With a large field of view, i.e., many sensors, partially obscured bottles (labels, food) can still be color sorted. Fully obscured objects are rejected (painted glass, ceramics.) The smaller the glass size, the greater the rejection rate due to less area in which to determine color. For the smaller glass size, additional mechanical handling problems will slow the process somewhat.

For the developmental machine currently being researched, only one size range will be sorted in order to establish and prove the color separating principle. Depending upon resources and success rates, modification of the color separation mechanisms and computer software will be made in order to establish the characteristics of smaller-sized objects.

A full production machine, marketable to cullet processors, will probably contain a sizing screen and three color heads for sorting bottles, half bottles, and quarter bottles.

Secondary Products

In the early 1970's much of the research into secondary products from glass waste was initiated by the Glass Container Manufacturers Institute (now called the Glass Packaging Institute) and Bureau of Mines. Since that early research period, secondary product development has proven to be technologically feasible.

One limitation to the use of secondary products is the lack of consistency of specifications for the material, such as performance, origin or composition. In setting specifications, the material generally has to be proven; however, without definitive specifications, manufacturers are reluctant to use new materials and, accordingly, rely on proven virgin materials. This aspect has limited the use of secondary products.

In addition, a steady supply of glass waste is not readily available for manufacturing secondary glass products. As discussed in Section 5, the commercial glass waste recovery systems are still in a developmental stage. Consequently, prior to any full-scale secondary product manufacturing attempt, there must be an available raw material supply.

Nevertheless, secondary waste glass products are a viable means of reducing overall glass wastes and research along those avenues warrants discussion.

One of the better publicized uses of glass waste is its utilization as an aggregate in bituminous concrete. Studies have been conducted to determine whether a glass-asphalt mixture could be designed to meet standard paving design criteria (147). It was found that satisfactory bituminous mixtures could be designed using aggregates composed entirely of crushed glass and that performance was not adversely affected by the slight degradation of the glass. However, some critics disagree with these findings (148).

Another application is the usage of ground glass aggregate in a slurry seal for pavement. Cured slurry surfaces, made with properly proportioned, acceptable aggregates and emulsions, provide effective seals for the road base against moisture penetration. Slurry aggregates contain crushed particles having wide ranges of sizes, so that when coated with asphalt they will pack together in such a way as to minimize the space to be filled with asphalt.

Laboratory research and testing demonstrated the feasibility of using glass in slurry material and that cured slurries containing glass will be equal to those containing the best natural stone (109). In addition, laboratory studies indicated that resistance to abrasion of cured slurries containing equal volumes of graded glass and expanded shale are equal or better than traditional slurry containing crushed stone aggregate. Glass in the slurry also improves the anti-skid characteristics of the pavement. Finally, it has been demonstrated that waste glass containing foreign materials, as well as crushed clean glass, can be utilized in the slurry sealant.

Glass waste as a substitute for conventional materials used in the construction market has gained interest. One such product is foamed glass construction material, made with waste glass and a foaming agent. The product may contain up to 95 percent of glass by weight. It features excellent thermal, sound and electrical insulating properties and can be used for roofing and wall insulation, acoustical tile, wall partitions, lightweight core material for metal or wood veneered panel and lightweight shipping containers (108).

A proposed manufacturing process for producing foamed glass consists of blending the carbonaceous residue formed by heat treating excreta with pulverized waste glass and heating the mixture, contained in a mold, under carefully controlled conditions (108). The excreta serves as the foaming agent. However, other foaming agents can be used.

An important facet to foam glass production is that the waste glass can contain foreign materials such as iron, aluminum, and organics. Table 36 lists the percentages by weight of foreign material found in the pulverized container glass used for glass foam. The size reduction of the waste glass containers can be accomplished by a crusher and ball mill in series. No sorting, grading, or preselecting is necessary prior to or after the final size reduction operation which reduces the glass and foreign materials to particle sizes in the range of 5 to 200 mesh. Other glass types can be used in the process. This suggests a possible use for any glass-rich fraction obtained from municipal solid waste.

Research has revealed another construction material utilizing waste glass. Construction panels made of varying proportions of salvaged glass combined with other materials such as demolition rubble and clay has proven to be competitive with large brick panels and precast concrete panels now used in building construction.

TABLE 36. FOREIGN MATERIALS FOUND IN CONTAINER GLASS USED IN FOAMED GLASS PRODUCTION

Foreign materials	Percent by weight in glass
Iron	0.1 to 3
Tin	0.1 to 2
Aluminum	0.1 to 2
Other Metals	0.1 to 1
Cellulosics	0.1 to 1
Other Organic Materials	0.1 to 1

A proposed manufacturing process for producing building or facing panels measuring 3 m x 1.2 m x 0.1 m (10 ft x 4 ft x 4 in) is based on a vibro-compaction casting technique, which utilizes a mixture of glass and rubble such as scrap brick, clay and water (104). The cast panels are dried and then fired in a tunnel kiln to yield the final product.

Experimental vibro-cast brick products were prepared and tested. Comparisons were made with standard high-strength concrete blocks of the same dimensions. Results indicate that all the experimental glass products fall into a high standard category when compared with structural clay products. The physical properties of the glass products compared favorably with the high-strength concrete blocks.

Waste glass has been successfully used in the production of mineral wool insulation. Uses for the product include mineral wool insulation batts and blankets, pouring or blowing wool, and high temperature felt insulation. Mineral wool is also used in the production of acoustical boards.

Use of waste container glass provides a simplified process as compared with traditional methods of manufacturing glass wool. Briefly, the process consists of the following operation steps (105):

1. Waste glass, mixed with three proprietary additive materials, is heated in a furnace to about 1,370 C (2,500 F) to produce molten glass;
2. the molten glass is poured into specially designed spinneret from which fibers are spun off and carried along by jets of steam; and
3. the fibers are cured and compressed to form mineral wool insulation materials.

Other research has indicated that fiber could be made using waste glass containing up to 20 percent foreign material. Organics were found to burn off, but it was necessary to tap the bottom of the furnace every 20 minutes to drain off any accumulated metals.

Physical properties of the wool product, using 50 percent glass waste, compared favorably with those of conventional wool products.

Another secondary product that has been investigated is the production of pressed ceramic tile made with waste glass and animal excreta (106). The processing phase of production is similar to that used to produce foamed glass. The major difference is that the mixed materials are charged to a mold and passed into a conveyor-type furnace equipped with a hydraulic press. Pressing of the mix during the heat treating operation is conducted to coalesce the filler with the glass particles and weld the glass and filler into a single mass.

Products, using 40 to 60 percent waste glass, have physical properties comparable with commercial tiles. The waste glass used can contain impurities similar to those used for foamed glass.

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